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Vehicular Mounted Mine Detector (VMMD) Test of Neutron Activation Technology

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PREFACE

This paper was prepared for the Director of Defense Research and Engineering, Office of the Under Secretary of Defense (Acquisition and Technology) under a task entitled "Technical Support to Communications and Electronics Command (CECOM) Night Vision and Electronic Sensors Directorate (NVESD) Mine Detection Program."

We would like to thank Dr. Frank Rotondo of the Institute for Defense Analyses and Dr. Tom Broach of the Night Vision and Electronic Sensor Directorate for their valuable contributions.

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EXECUTIVE SUMMARY

A. BACKGROUND AND SCOPE

The Vehicular Mounted Mine Detector (VMMD) ATD demonstration occurred in June 1998 at Aberdeen Proving Ground, Maryland, and in July 1998 at Socorro, New Mexico. It was decided that it would be beneficial to devote a small amount of that time to conducting a series of tests specific to the Thermal Neutron Analysis (TNA) detector being used by Computing Devices Canada (CDC). In April 1998, a TNA-specific test plan was devised to address performance issues in a more thorough and systematic manner than had been done in the past. Unfortunately, there were sufficient constraints such that this test plan could not be implemented as designed. Instead, a much abridged version was conducted at Aberdeen Proving Ground. At Socorro, the test that was actually conducted yielded only a P_D / P_{FA} value and hence was not scientifically interesting. Thus, in this report we focus most of our attention on the Aberdeen results.

B. TEST RESULTS

1. Aberdeen Proving Ground, Maryland

The main results from the APG test are as follows:

- CDC obtained a P_D of 63 percent (12 out of 19 mines detected) and a P_{FA} of 0 percent (0 out of 22) using a threshold value CDC selected for the decision criterion. This threshold was nonoptimal; the receiver operating characteristic (ROC) curve (see Figure ES-1) indicates that a P_D of 79 percent (15 out of 19 mines) with a P_{FA} of 0 percent was possible with the optimal choice of the threshold. The ROC performance curve was insensitive to alternative decision criteria.
- Surface mines were more likely to be detected than buried mines, although one surface mine went undetected.
- Performance showed no dependence on depth.
- Performance showed no dependence on mine type (or nitrogen content).
- Three mines yielded very low signatures: an M19 at 1.5 in., a TM62P on the surface, and a TM46 at 2 in.

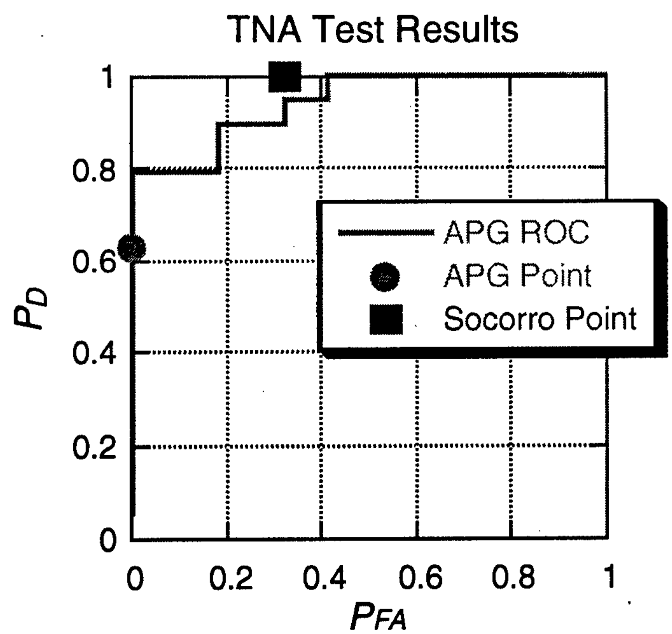

Figure ES-1. ROC Curves for Aberdeen and Socorro Tests

- It is possible that the square shape of an M19 renders it more difficult to detect. An M19 on the surface yielded the second weakest signal of all the surface mines; its signal was even weaker than those of a TM62M and a TMA4, both of which contain significantly less nitrogen than an M19. Furthermore, during a separate reproducibility test, an M19 at 1.5 in. twice yielded a significantly weaker signal than an M15 at 1.5 in., even though the M15 contains only 10 percent more nitrogen than an M19.
- Target variability played a larger role than background variability in detection rate.
- Test execution shortfalls preclude resolution of key issues.

2. Socorro, New Mexico

As noted above, quantitative analysis was essentially impossible given the lack of data obtained at Socorro. The only result that can be reported is a P_D of 100 percent (19 out of 19 mines detected) and a P_{FA} of 32 percent (6 out of 19).

C. CONCLUSIONS AND RECOMMENDATIONS

The Aberdeen Proving Ground tests yielded several interesting results. First, target signature variability dominated the test results. This was surprising, given that usually the background phenomenology dominates TNA performance. Second, target

shape may be an important driver, as indicated by the relatively poor detectability of the M19. Finally, that the detectability of a mine did not seem to depend on either its burial depth or its nitrogen content is counterintuitive. Unfortunately, conclusions about these results can only be drawn with extreme caution; it may be that some or all are simply an artifact of an extremely small data set. Aspects of the test plan that were intended to shed light on exactly these types of issues were not completed. We believe that it is in the Army's interest to resolve these issues with a more thorough test, such as the one detailed in Appendix A of this report.

I. INTRODUCTION

The Vehicular Mounted Mine Detector (VMMD) ATD demonstration occurred in June 1998 at the Aberdeen Proving Ground (APG), Maryland, and in July 1998 at Socorro, New Mexico. It was decided that it would be beneficial to devote a small amount of time during the demonstration to a series of tests specific to the Thermal Neutron Analysis (TNA) detector being used by Computing Devices Canada (CDC). The primary goal of these TNA-specific tests was to address performance issues in a more thorough and systematic manner than had been done in the past. In April 1998, a test plan was devised to address four major objectives: (1) the amount of soil content variability to be expected on-site; (2) measurement reproducibility, on both a short and long time scale; (3) the spatial response of the device; and (4) the generation of performance curves, or receiver operating characteristic (ROC) curves (P_D vs. P_{FA}), for different mine types and depths.

The first objective is important for two reasons: first, soil content variability on a small scale renders background subtraction difficult; and second, large concentrations of certain isotopes can cause problems directly or indirectly. For example, a high nitrogen concentration in the soil can interfere directly with the TNA detector's ability to detect the γ-rays emitted by nitrogen in the explosive. In addition, γ-rays generated by neutron capture by several isotopes can cause pile-up in the detectors. The second objective addresses the "system noise level" of the device. The third objective addresses the fact that TNA is a confirmatory sensor and as such, it will be cued by other sensors. The spatial accuracy of the cuing device must therefore be compatible with the spatial response of the TNA device. The fourth objective provides an understanding of how performance depends on nitrogen content and depth.

Appendix A details this test plan. Unfortunately, there were sufficient constraints such that this test plan could not be implemented as designed. Instead, a much abridged version was conducted at APG. At Socorro, the test actually conducted yielded only a P_D / P_{FA} value and hence was not scientifically interesting. Thus, we focus most of our attention on the Aberdeen results in this report.

As will be seen in the Test Implementation section, only three of the four objectives of our original test plan were even attempted. The spatial response test was not

conducted. Further, the reproducibility test addressed only the short time scale, and even then, it was insufficient. For the performance curves, only 41 targets were measured, 19 of which were mines. Thus, although we present a ROC curve as well as figures displaying performance dependence on nitrogen content and depth, one must be very careful not to draw too many conclusions from such a limited data set.

For a detailed description of the TNA system employed by CDC, the reader is referred to Dr. John McFee at the Defence Research Establishment, Suffield. In brief, the TNA sensor consists of an isotopic Cf^{252} neutron source and a moderator that slows the neutrons down to near-thermal energies before they penetrate the ground. Four NaI detectors surrounding the source detect the 10.8 MeV γ-rays emitted by the nitrogen in the explosive. The detection window extends from 10.05 MeV to 11.30 MeV, so that a significant number of counts in the window are due to contributions from background rather than from the nitrogen in the explosive. This background contribution is subtracted off by using background spectra collected in places where it is known that no mine is present. Contributions to this background include a 10.6 MeV γ-ray generated by Si in the soil, pile-up resulting from γ-rays produced by neutron capture off various elements in the soil, fast-neutron capture in the NaI detectors, and cosmic rays.

II. TEST IMPLEMENTATION

Due to time and other constraints, the full TNA test plan detailed in Appendix A could not be implemented during the VMMD tests. Here, we describe the tests that were actually implemented at APG and at Socorro. Table II-1 shows the accomplishments relative to the goals.

Table II-1. Test Accomplishments Relative to Goals

Category	Goal	Aberdeen	Socorro
Soil analysis	minerals CNOH water density	minerals CNO	CNO
Reproducibility	20	9	0
Spatial Response	100	0	0
Declarations	80	41	39
Confidence Measure	80	41	0
Spectra	80	0	0

A. ABERDEEN PROVING GROUND

On the morning of 17 June 1998, CDC completed a significantly scaled-down version of a "repeatability" test. Four locations were marked in Lane 11 with both painted crosses and golf tees. At each location, CDC took measurements for 2 minutes. They then moved forward several meters beyond the fourth location, backed up, and repeated the measurements at each location in reverse order. Thus, a total of eight measurements were made, two at each of the four locations.[1] Although it is not possible to draw any quantitative conclusions about the repeatability of the TNA platform from this data set, we offer qualititative conclusions in the Test Results section. Figure II-1 shows the ground truth of this test. An M15 was buried 1.5 in. below Location 1. At Location 2, a large object had been dug out and the soil replaced, thereby creating an area less dense than the surrounding soil. Location 3 was undisturbed soil. An M19 was buried 1.5 in. below Location 4.

1 Location 1 was actually measured three times, yielding a total of nine measurements.

On the morning of June 19, 1998, CDC completed measurements, each lasting 2 minutes, at 41 specified locations. The time required to complete the test was about 3.5 hours. This time includes the time required to move and align the system, as well as that required to repeat several background and calibration measurements. Of the 41 sites, 19 were mines of various nitrogen content and depth (see Table II-2). The last column of Table II-2 indicates how many of each mine were detected by CDC. Although 41 data points is not a sufficent number to accurately characterize the dependence of system performance on nitrogen content and depth, we draw some conclusions and present them, along with the ROC curve, in the Test Results section.

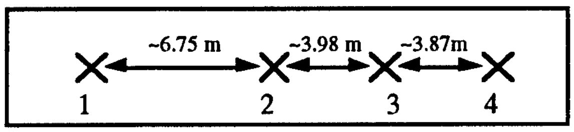

Figure II-1. Repeatability Test Layout

Table II-2. Inventory of Mines for ROC Curve Test

Mine Type	Depth	Nitrogen Content (kg)	Quantity	Number of CDC Detects
M15	Surface	3.08	2	2
M15	1.5 in.	3.08	3	3
M19	Surface	2.85	1	1
M19	1.5 in.	2.85	3	1
TM62M	Surface	1.58	2	2
TM62P	Surface	1.33	1	0
TM62P	3 in.	1.33	2	1
TM62M	4 in.	1.58	2	1
TM46	2 in.	1.06	1	0
TMA4	Surface	1.02	1	1
TMA4	2 in.	1.02	1	0

It should be noted that at both Aberdeen and Socorro the marked coordinates of the mines correspond to the center of the mine; there is no offset in the designation relative to it. Therefore, the survey should be accurate to within a few centimeters. Any offset in the placement of the apparatus relative to the mine is a result of the manual alignment of the TNA system, and is presumably small. Further, for those mines not on the surface, mines of a given type are buried at the same depth. So to first order, the

attenuation of neutrons and γ rays is the same for mines of a given type. Finally, all mines of a given type are presumed to have fixed composition, especially with respect to nitrogen content.

B. SOCORRO

On July 23, 1998, CDC completed a truncated test of the TNA system. Neither the planned reproducibility test nor the spatial response test was attempted. Moreover, due to the absence of key personnel, only yes/no responses were generated, instead of confidence reports. Thus, very little analysis of the test results is possible.

The test was conducted on lanes 11, 12, and 13 at the Socorro facility. The test consisted of measurements taken for 2 minutes at each of 38 designated locations. At 9:00 a.m., the initial calibration measurement was completed and the first background measurement started. The test was completed at 12:22 p.m. Thus, the total time required per test measurement was 5 minutes and 20 seconds. This includes the time to move and align the system, as well as overhead for several background measurements and recalibrations.

Of the 38 designated locations, 19 locations corresponded to buried mines containing explosive charges. Table II-3 gives the mine inventory for the Socorro test. This inventory is similar to that of the Aberdeen test, except that no surface mines were included. The other 19 locations were at least 4 m from any buried mine, with or without explosives.

Table II-3. Inventory of Mines for the Socorro Test

Mine Type	Depth (in.)	Nitrogen Content (kg)	Quantity	Number of CDC detects
M15	1.5	3.08	4	4
M19	1.5	2.85	3	3
TM62M	4	1.58	3	3
TM62P	3	1.33	3	3
TM46	2	1.06	3	3
TMA4	2	1.02	3	3

III. TEST DATA

We have scored and analyzed the set of response data provided by CDC. In this section we explain the meaning of the data, document CDC terminology, and explain various checks that we have performed to ensure that the data set is self consistent and that our interpretations are correct.

The procedure outlined here has been applied to the entire database. The single test measurement shown in Figure III-1 will serve as an example for this discussion. Note there are four independent γ-ray detection subsystems, or "channels," labeled 0...3, in the system; the "sum" channel is a function of the four independent channels.

```
>------------------------------------------------------------------------
>Target  302  ab302  t=120  sec  Bckgnd  abbg01  t=300  sec  Energy  cal
=abecal01
>
>Chan #     net  counts    bckgnd  counts     var  net  counts     var  bckgnd
counts
> 0           29.9          105.1           177.8                 42.8
> 1          102.0          108.0           253.0                 43.0
> 2           25.8           61.2           112.0                 25.0
> 3           19.7           83.3           137.2                 34.2
>
>Channel     Net         Std Net     P(alpha)
>  0         29.91       13.33       0.012
>  1        102.03       15.91       0.000
>  2         25.82       10.58       0.007
>  3         19.73       11.71       0.046
>  sum      177.49       26.08       0.000
>------------------------------------------------------------------------
```

Figure III-1. A Sample Test Data Record as Provided by CDC

A brief description of the measurement protocol will help to understand and interpret the data shown here. There are three types of measurements that are taken in the course of the test: calibration, background, and test measurements. Each measurement yields an energy spectrum of γ-rays. The purpose and interpretation of each measurement follows.

- At the beginning of the test, and periodically thereafter, a standard target is used to collect an energy *calibration* measurement. This calibration is used to monitor and compensate for any drift in system gain that might be expected (for example, from changes in the temperature of the photomultiplier tubes).

The spectrum determines the limits on the pulse height window corresponding to the location of the 10.8 MeV nitrogen peak. This window determines the interval over which the spectra will be summed in subsequent measurements. The procedure is applied upstream of the data reported here, and will not be discussed further.

- At the beginning of the test, and periodically thereafter, a 5-minute *background* measurement is made at a location where there is no mine. This measurement is used to compensate for any long-range (on a scale of several tens of meters) variations in the soil. This spectrum will be normalized to, and subtracted from, the subsequent test measurements.
- A *test* measurement is made by counting for 2 minutes at each designated test location.

Thus, the purpose of the calibration and background measurements is to properly correct each test measurement. For each test measurement, there are essentially three independent numbers for each of the four channels:

- N, the integer number of counts in the nitrogen window for the 2-minute test measurement;
- NB, the integer number of counts in the same window from the previous 5-minute background measurement; and
- c, the normalization constant determined by matching the test spectrum with the previous background spectrum in some region outside the nitrogen window. This number should be close to 0.4, the ratio of the counting times, if the soil properties do not vary.

The data provided by CDC do not contain these raw numbers, but intermediate results based on them. All of the numbers in Figure III-1 can be derived from N, NB, and c; however, we can invert the process and back them out from the data provided. The bullets that follow define the relationship between the raw data and the data provided. Refer to Channel 0 in the data record above for the numbers presented here.

- `net counts` = N – c*NB and `bckgnd counts` = c*NB, so N = `net counts` + `bckgnd counts` = 135.0, an integer.
- `bckgnd counts` = c*NB and `var bckgnd counts` = c^2*NB, so c = `var bckgnd counts`/`bckgnd counts` = 0.407 ~ 0.4, as suspected. [This follows from the fact that for the Poisson distribution, var(COUNT) = COUNT, and so var(const* COUNT) = const^2* COUNT.]
- Further, NB = `bckgnd counts`^2/`var bckgnd counts` = 258.08, an integer to the precision quoted.
- As a check, observe that `var net counts` = N + c^2*NB, as it must.

- `Net` is just `net counts` to better precision.
- `Std Net` = SQRT(`var net counts`), as it must.
- `P(alpha)` is 1 minus the cumulative normal distribution of `Net/Std Net`. It is the probability that the null hypothesis ("no mine here!") is rejected.

Thus, the ratio of `Net/Std Net` is being interpreted as the z-score based on counting statistics. The implicit assumption is that in the absence of mines the variation in this quantity should be dominated by counting statistics. If this assumption is correct, this set of numbers, corresponding to the locations where there is no mine present, should have zero mean and unit standard deviation.

Now refer to the row labeled `sum`:

- `Net` is the sum of the four numbers above it.
- `Std Net` is the sum in quadrature of the four numbers above it.
- `P(alpha)` is 1 minus the cumulative normal distribution of `Net/Std Net`, as before.

It is noted elsewhere in the CDC database that the decision criterion, called "P_{min}", is derived by taking the minimum of the five numbers in the `P(alpha)` column. For this test, the threshold value for P_{min} was 0.001; below that value a mine was declared, and above it no mine. In the analysis, we find that this decision criterion gives performance that is not significantly different from other reasonable criteria based on this data.

So, to summarize, each row of the database can be derived from three numbers: N is the number of counts at the given location in the nitrogen window. NB is the number of counts in the background spectrum in the same window; this number only changes when a new background or calibration spectrum measurement is taken. c is the normalization constant; it changes based on spectral counts outside the nitrogen window, but is always within a few percent of the ratio of the counting times for N and NB.

IV. TEST RESULTS

A. ABERDEEN PROVING GROUND

1. Repeatability Test

Table IV-1 gives the main results of the CDC TNA repeatability test. The parameter "P_{min}" is the statistic used by CDC to determine whether a mine is present. It is essentially 1 minus the cumulative normal distribution of the net counts divided by the standard deviation of those counts, or the probability that the null hypothesis is not rejected. The "min" refers to the fact that this value is calculated in each of the four detectors, so that a detection is declared if P is less than a threshold value in any one detector or in the summed channel. (The threshold value for the repeatability test was 0.02.) P_{min} is strongly correlated with the the total net counts (summed over the four detectors) divided by the total background counts. This statistic is labeled "net/bckgnd" in Table IV-1.

Although a test yielding only two measurements per location does not allow for a quantitative assessment of the repeatability of the TNA system, the assumption that the system yields repeatable results is not inconsistent with the results displayed in Table IV-1.

Table IV-1. Results of Repeatability Test

Location	1	1	1	2	2	3	3	4	4
Run #	1	2	3*	1	2	1	2	1	2
Back counts	396.6	374.8	383.4	396.3	375.7	392.2	373.60	384.6	383.1
Net counts	102.38	117.27	129.62	–34.33	–20.67	27.90	17.55	53.39	68.96
Net/bckgnd	0.258	0.313	0.338	–0.0866	–0.0550	0.0711	0.0470	0.139	0.180
P_{min}	0.000	0.000	0.000	0.567	0.359	0.123	0.219	0.014	0.003
Mine? (Y/N)	Y	Y	Y	N	N	N	N	Y	Y

* Location 1 was measured three times.

Two results from this test merit comment. First, while the M15 and M19 contain very similar amounts of nitrogen, and they were buried at the same depth, the M15 signal

was significantly stronger than that of the M19. Taken alone, this result may not be statistically significant, but a similar trend emerged in the ROC curve test results as well (see below). Second, the TNA system indicated a significant difference between locations 2 and 3. Specifically, the net signal from location 2 was found to be much lower than that of location 3, consistent with the fact that location 2 was a hole that had been filled and was therefore less dense than location 3.

2. Receiver Operating Characteristic Curves and Decision Criteria

As discussed in the Test Data section, the CDC team constructed variables called "P-statistics" to determine whether a mine was present. The CDC decision criterion is the P_{min} statistic. This is simply the minimum of five P statistics: one for each of the four γ-ray detectors in the system and one for the sum of all four. Figure IV-1 shows the ROC curve results using the P_{min} statistic as well as two alternative statistics discussed below.

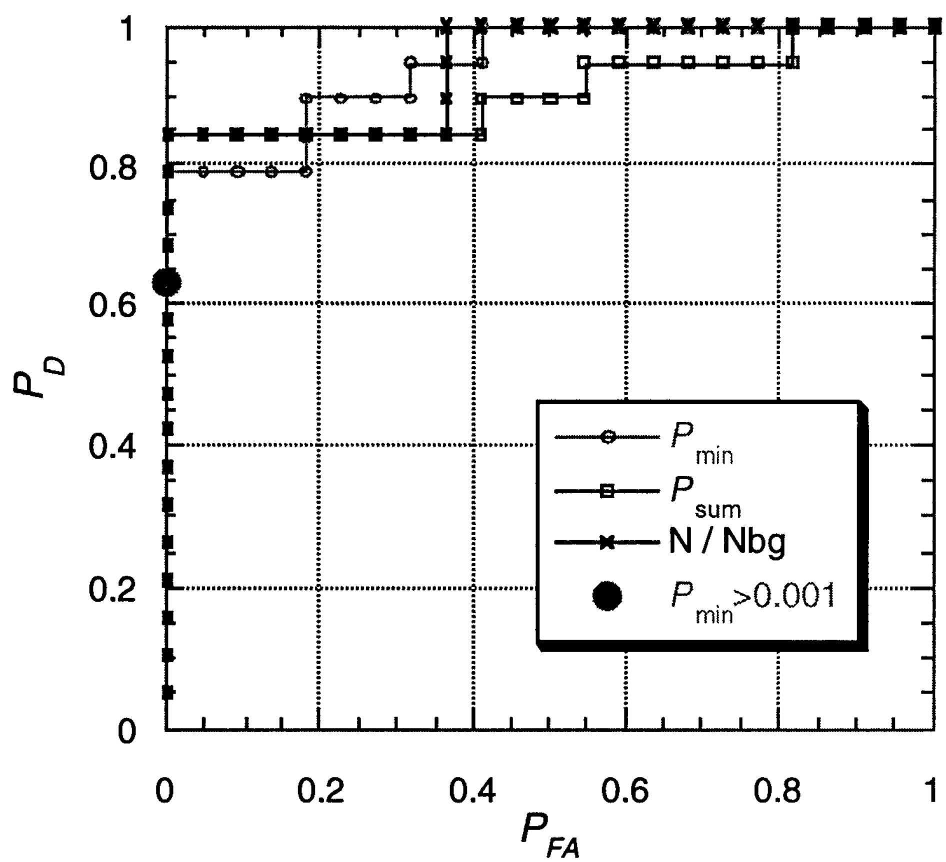

Figure IV-1. ROC Curves Corresponding to Alternative Decision Criteria for the Aberdeen Data

The CDC team chose a nonoptimal threshold value of P_{min}, and hence they "detected" only 12 of the 19 mines, with no false alarms. However, as can be seen by the ROC curve, a more optimal choice of P_{min} would result in the detection of 15 mines with no false alarms.

We have investigated the performance of several simple alternatives to this criterion. Two such alternatives are shown in Figure IV-1. One of these, P_{sum}, is just the P statistic associated with the sum of all four detectors. Relative to P_{min}, this statistic gives insignificantly better performance at low false-alarm rates and marginally worse performance overall. The other alternative, N/Nbg, is just the ratio of the sum counts to the sum background counts. It is analogous to P_{sum}, but it neglects the spectral normalization step. This decision criterion gives overall performance identical to P_{min} (in the sense that the areas under the curves are the same).

That these alternative decision criteria give similar results should be interpreted as evidence that the demonstrated level of performance is not overly sensitive to the particular choice of algorithm. Given the level of statistical significance of this test, it would be unsettling to find that the relatively subtle distinctions that we have explored here make a significant difference.

Whichever decision criterion one adopts, study of the data reveals that there are three particularly difficult targets: an M19 at 1.5-in. depth, a TM62P on the surface, and a TM46 at 2-in. depth. Figure IV-2 shows the N/Nbg signature statistic as measured in sequence. The blue triangles show the ground truth. Note that each mine in question is surrounded by mine-free locations that have nearly identical signatures; it is difficult to see how these mines could be "pulled out" of the background.

3. Depth

Figure IV-3 shows a plot of `net/bckgnd counts` versus depth. While four of the surface mines had very strong signatures, the signals of the buried mines show no dependence on depth. Note, however, that there is an unknown error bar on each depth; that is, each mine was buried at the approximate depth indicated, but the exact depth of each mine is not known.

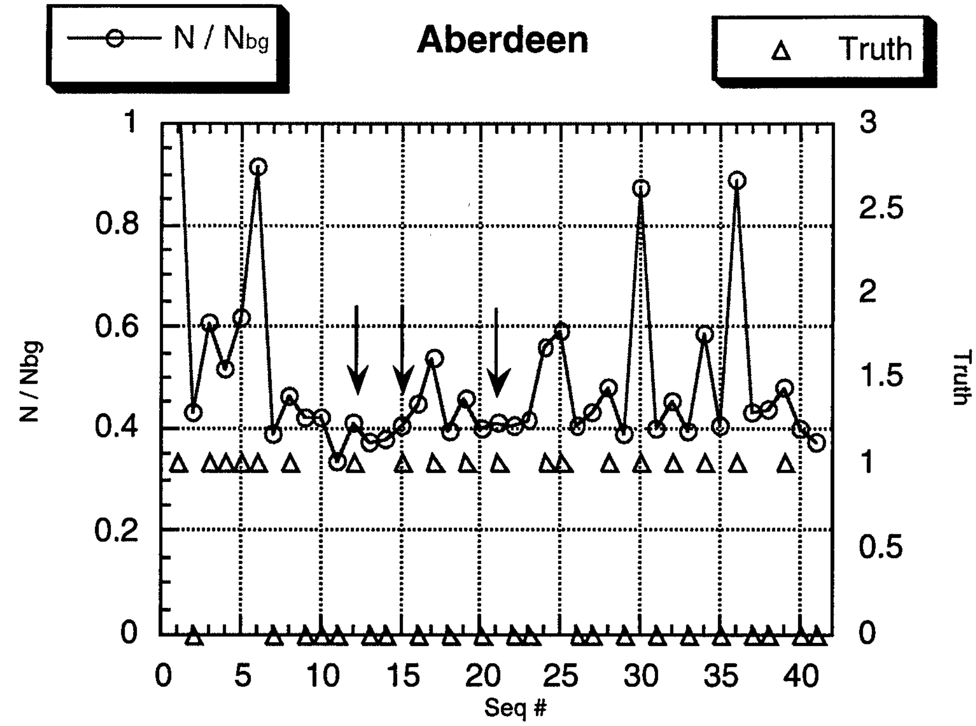

Figure IV-2. N/Nbg Signatures in the Sequence Measured at the Test. The three difficult cases are indicated by arrows. From left to right they are TM62P @ 0 in., TM46 @ 2 in., and M19 @ 1.5 in.

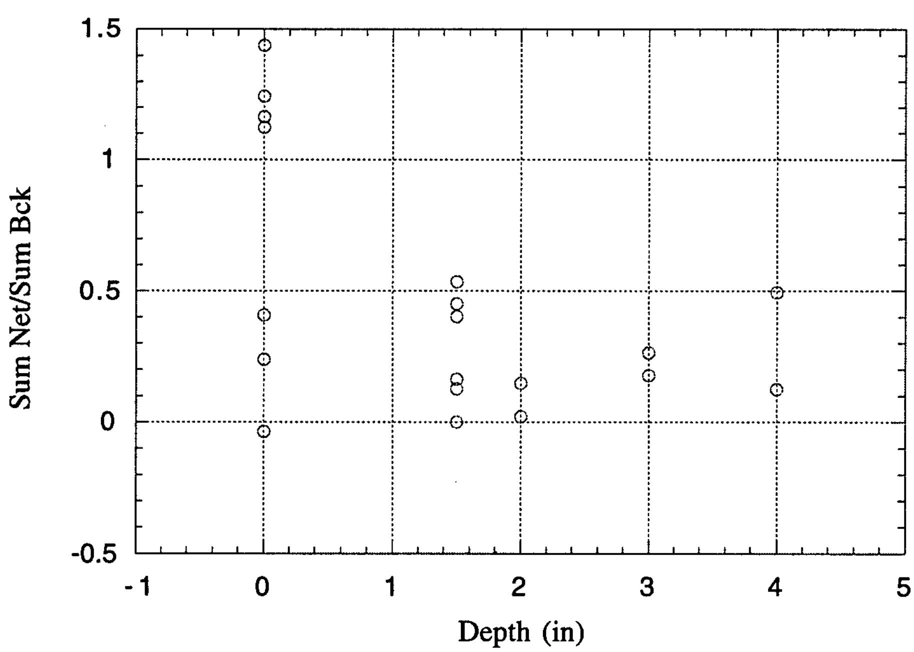

Figure IV-3. Dependence of Performance on Mine Depth

4. Nitrogen Content

Figure IV-4 shows the dependence of `net/bckgnd counts` on nitrogen content. There does not seem to be any significant dependence on nitrogen content. Table IV-2 gives our computation of nitrogen content of the various mine types.

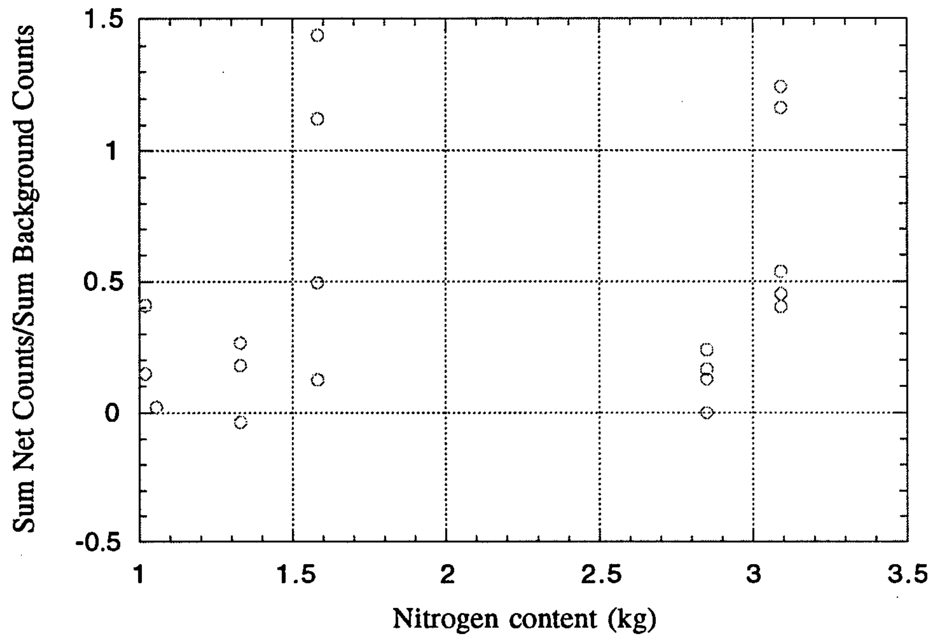

Figure IV-4. Dependence of Performance on Nitrogen Content

Table IV-2. Nitrogen Content of Various Mine Types

Mine Designation	Explosive Type	Explosive Weight (kg)	Nitrogen Mass Fraction	Nitrogen Weight (kg)
TM62M	TNT/RDX/ Alumimum	7.0	0.226	1.58
TM62P	TNT	7.2	0.185	1.332
TMA4	TNT	5.5	0.185	1.018
M19	Comp B	9.53	0.299	2.851
M15	Comp B	10.3	0.299	3.081
TM46	TNT	5.7	0.185	1.055

5. Variability of Background Signature

One of the objectives of this test was to determine the effect of background variability. In this section we limit our attention to the test locations where there was no mine present. We address the question of whether the results tell us anything useful about the background.

We first look at the raw number of counts, N, as a function of the sequence in which the measurement was made. We choose to use this statistic here and in the following discussion because the expected "statistical" variation of this quantity is widely understood and easy to compute (square root of N). See Figure IV-5 to verify that the variation in the data seems somewhat large compared to the error bars on the points (which are square root of the counts), but not excessively so. If we look at the ratio of the variance to the mean of these 22 samples, we get a value of 2.4; this is significantly larger than the value of 1 that is expected for a Poisson process with a well-defined mean value.

In fact, the variability has some systematic behavior; there is a long-term trend to higher number of counts with time, a transition at the fifth measurement, and few real outliers. Thus it is possible that the periodic background measurements and recalibration account for much of this variation. This is indeed the case; as shown in Figure IV-5, the solid line, which represents the background measurements, tracks the points quite well. Therefore, we expect that the ratio of Net/Std Net, from which P_{tot} is derived, to be normally distributed with zero mean and unit standard deviation. The actual values are 0.13 and 1.12, well within expected errors of the nominal values. Thus, the CDC background subtraction protocol successfully removes much of the background variance in this test.

Additional verification that the background variation is dominated by counting statistics is provided by the lack of correlation among the individual γ-ray channels. The cross-correlation coefficients are shown in the table below; all are consistent with a lack of correlation.

Correl. Coef.	Channel 2	Channel 3	Channel 4
Chan 1	–0.25	0.02	0.07
Chan 2		0.15	–0.10
Chan 3			0.08

So it seems that, in this test, the background and recalibration measurements that are conducted as part of the CDC measurement protocol successfully mitigate the variation of the background. The central question then becomes, Is the variation a variation in the signature—that is, is it a property of the location—or is it simple instrumental drift? The original test protocol specifically addressed this question in the reproducibility test. Unfortunately, this part of the reproducibility test was not performed.

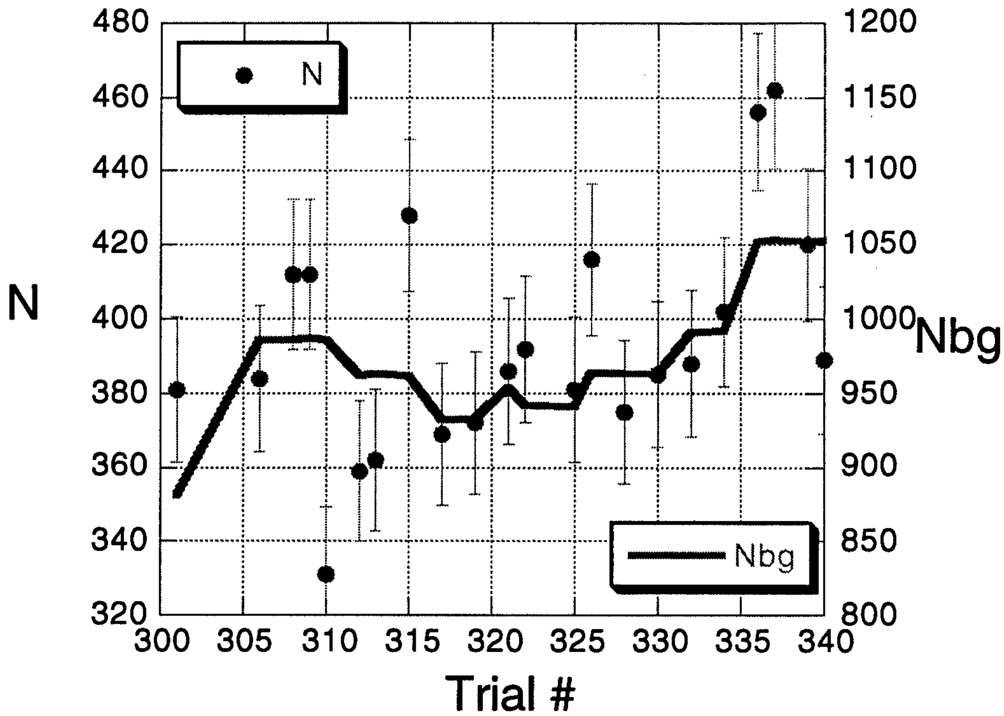

Figure IV-5. Raw Number of Counts for Measurements at Locations without Targets. The points represent cued locations, and refer to the left axis. The line represents background measurements, and refers to the right axis. The axes are scaled by a 2:5 ratio, corresponding to the relative durations of the measurements.

6. Variability of Target Signature

As we discussed above, the response of the TNA system to the background seems to be under control. In this section we apply similar consideration to the mines. Unfortunately, the sample size was much smaller than desired, and the variety of mine types was rather large. It is therefore difficult to draw statistically valid conclusions based on controlled variables. What data we have are represented in Figure IV-6. It is clear, however, that the target signatures exhibit a large variability relative to that of the background.

In Figure IV-6, the closed circles show the mean response in total counts, N, by mine type and depth. Values of N corresponding to the symbols should be read off the left-hand axis. The mine groups are labeled by mine type @ depth, with "S" in the depth field denoting a surface mine. (Note that "surface" means that no part of the mine was below ground level.) The mine groups are arranged along the horizontal axis with the surface mines on the left, the buried mines next, and the point corresponding to the 22

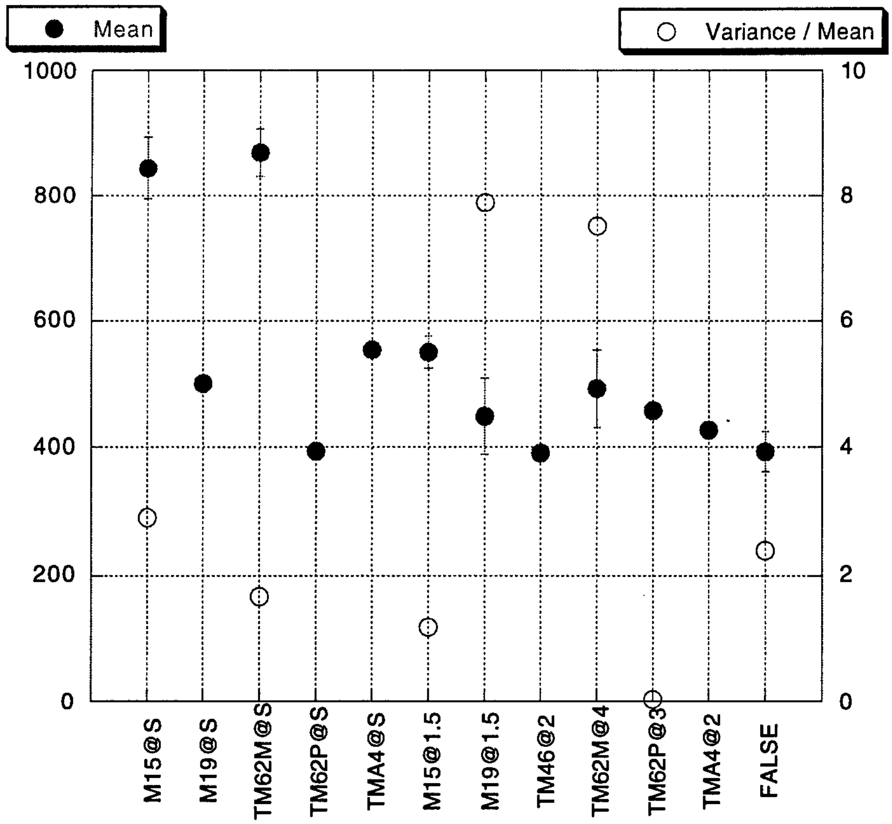

Figure IV-6. Mean Number of Counts and Variance-to-Mean Ratio by Mine Type and Depth. For explanation see text.

false locations on the right. The error bars on these points indicate plus and minus one standard deviation of the set of targets. Some points have no error bars; these correspond to "groups" of a single mine.

Each open circle represents the variance-to-mean ratio for a fixed mine type at fixed depth. Cases without open circles are samples of one, where no variance estimate exists. Variance-to-mean values should be read off the axis on the right. Recall that this ratio is expected to be unity for processes where the variability is dominated by Poisson counting statistics. Note that there are two groups, namely M19 @ 1.5 in. and TM62M @ 4 in., that have quite large values of variance to mean. It is possible that the explanation for this lies in the different soil properties at the locations of the mines.

It is likely, however, that some other source of variation is in play. The evidence for this view is the behavior of the surface mines. Note first that the TM62P @ S mine was indistinguishable from background level (defined by the "false" cues), while the buried versions of the same mine had signals somewhat above background. Further, note that the M19 @ S mine had a much smaller signature than the two M15 @ S—about a

factor of four in counts above background—even though these two mine types are fairly similar in terms of nitrogen content.

Based on the variability of the target signatures, especially the surface targets, and the lack of variability of background signature, we suspect that the variability in target signature may be due to extreme sensitivity to the placement of the TNA system relative to the mine. For example, the path from mines (especially those on the surface) to the gamma detectors may be partially obstructed by the shielding. (This seems to be the case based on line drawings of the CDC sensor head.) It is possible that the degree of obstruction of the mine depends critically on the elevation and orientation of the detection head. Note that the response of the ground—an extended, homogeneous entity—would not be so sensitive to the geometry. It is also likely that the shape of the M19 (square) plays a role in the variability.

7. Soil Content

Approximately 2 weeks before the TNA tests were conducted, soil samples were collected roughly every 15 m along the test lane. Near the center of the lane, five soil samples were taken at a separation distance of about 6 in. (see Figure IV-7). Table IV-3 summarizes the results of the composition analysis in the test lane.

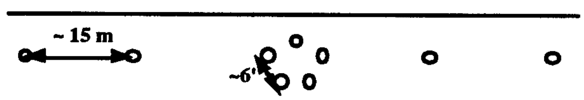

Figure IV-7. Soil Sampling Layout

For several of the elements, Figure IV-8 compares the composition by weight averaged over the test lane with the average values cited for Earth's crust.[2] The APG test lane contained a significantly reduced percentage of Al, Ca, Fe, K, Na, and Ti compared to Earth's crust average values. Such soil conditions work in favor of TNA detection systems, because all of those elements contribute to pile-up, particularly through radiative capture, which for each of these elements produces γ-rays of at least 7 MeV.[3]

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2 Available: http://www.shef.ac.uk/chemistry/web-elements/index.html, February 1999.

3 Fe^{56} is 91.7 percent of naturally occurring Fe and has a capture cross-section of 2.81 b, yielding a 7.65-MeV γ-ray; Fe^{54} is 5.9 percent of naturally occurring Fe and has a capture cross-section of 2.16 b, yielding a 9.30-MeV γ -ray; Al^{27} has a 0.23 b capture cross-section, yielding a 7.73-MeV γ -ray; Ca^{40} has a 0.41 b capture cross-section, yielding an 8.36-MeV γ-ray; K^{39} is 93.3 percent of naturally occurring K and has a 2.10 b capture cross-section, yielding a 7.80-MeV γ-ray; K^{41} is 6.7 percent of

Table IV-3. Percent Composition by Weight

Sample	1	2	3	4	5-1	5-2	5-3	5-4	5-5	6	7	8	9	10
Aluminum	1.1	1.6	1.2	1.2	1.4	1.5	1.3	1.2	1.3	1.5	1.8	1.3	1.3	1.4
Calcium	1.3	1.4	1.2	1.6	1.7	1.5	1.5	1.3	1.8	1.6	1.6	1.3	1.4	1.6
Iron	1.0	1.1	1.0	1.2	1.7	1.3	1.2	1.2	1.2	1.6	1.1	1.3	1.2	1.3
Potassium	0.05	0.07	0.06	0.05	0.08	0.07	0.06	0.07	0.06	0.07	0.09	0.07	0.05	0.06
Silicon	24	23	24	25	26	20	22	23	24	21	23	24	22	24
Sodium	0.06	0.08	0.06	0.07	0.08	0.08	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.08
Titanium	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02
Nitrogen	0.11	0.12	0.07	0.14	0.05	0.44	0.32	0.19	0.08	0.31	0.18	0.04	0.00	0.00
Carbon	0.36	0.25	0.44	0.17	0.31	0.10	0.03	0.22	0.52	0.25	0.45	1.26	1.03	0.39

Figure IV-9 compares the concentration of nitrogen and carbon averaged over the test lane with Earth's crust average values. The nitrogen concentration in the test lane was almost two orders of magnitude greater than the average value cited for Earth's crust, while the carbon concentration in the test lane was about a factor of two higher. The higher the nitrogen content, the greater the potential for problems for a TNA detection system, particularly if there is a great degree of spatial variability of the nitrogen content, which appeared to be the case for this test lane, as seen in Table IV-3.[4] Although there were other lanes at APG that were found to have essentially no nitrogen, the TNA system was not tested on those lanes, so it is not possible for us to determine whether the levels of nitrogen in the test lane had any significant impact on the performance of the system.[5] In the future, it would definitely be worthwhile to take advantage of the apparent variability of nitrogen content on the APG site to test the sensitivity of the TNA detection

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naturally occurring K and has a 1.46 b capture cross-section, yielding a 7.53-MeV γ-ray; Na^{23} has a 0.53 b capture cross-section, yielding a 6.96-MeV γ-ray; Ti^{48} is 73.8 percent of naturally occurring Ti and has a 7.84 b capture cross-section, yielding an 8.14-MeV γ-ray; Ti^{46} is 8 percent of naturally occurring Ti and has a 0.60 b capture cross-section, yielding an 8.88-MeV γ-ray; Ti^{47} is 7.3 percent of naturally occurring Ti and has a 1.70 b capture cross-section, yielding an 11.63-MeV γ-ray; Ti^{49} is 5.5 percent of naturally occurring Ti and has a 2.21 b capture cross-section, yielding a 10.94-MeV γ-ray; and Ti^{50} is 5.4 percent of naturally occurring Ti and has a 0.18 b capture cross-section, yielding a 6.37 MeV γ-ray.

4 The average percent composition by weight of nitrogen over the lane was 0.146 percent, with a standard deviation of 0.131 percent.

5 Soil samples were actually collected over the entire site, because at the time the samples were collected, it was not known which lanes would be used for the TNA test. It was found that there were several test lanes for which the percent composition of nitrogen was 0.00.

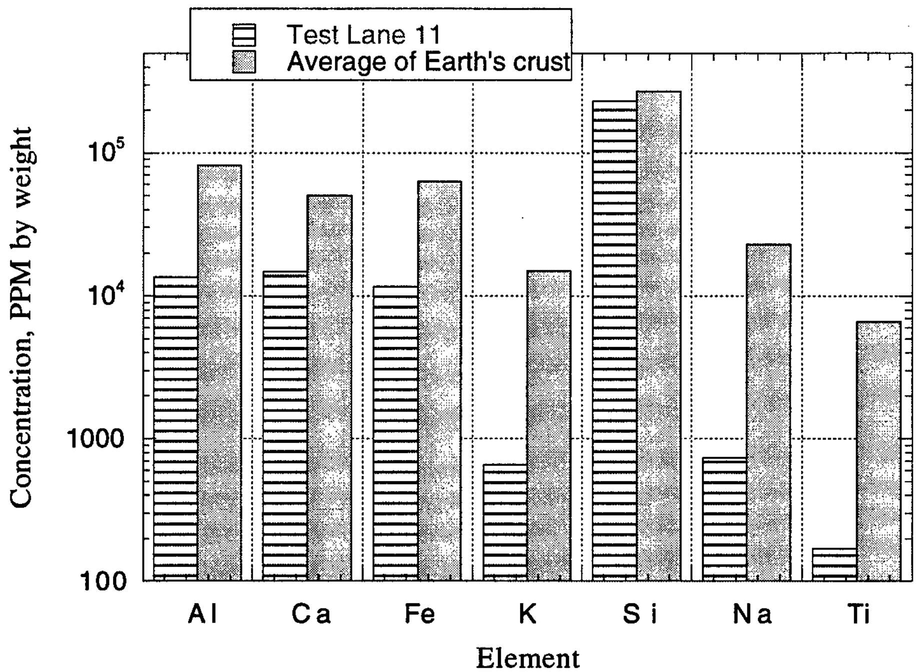


Figure IV-8. Soil Composition, Lane 11 and Earth's Crust (avg): Aluminum, Calcium, Iron, Potassium, Silicon, Sodium, and Titanium

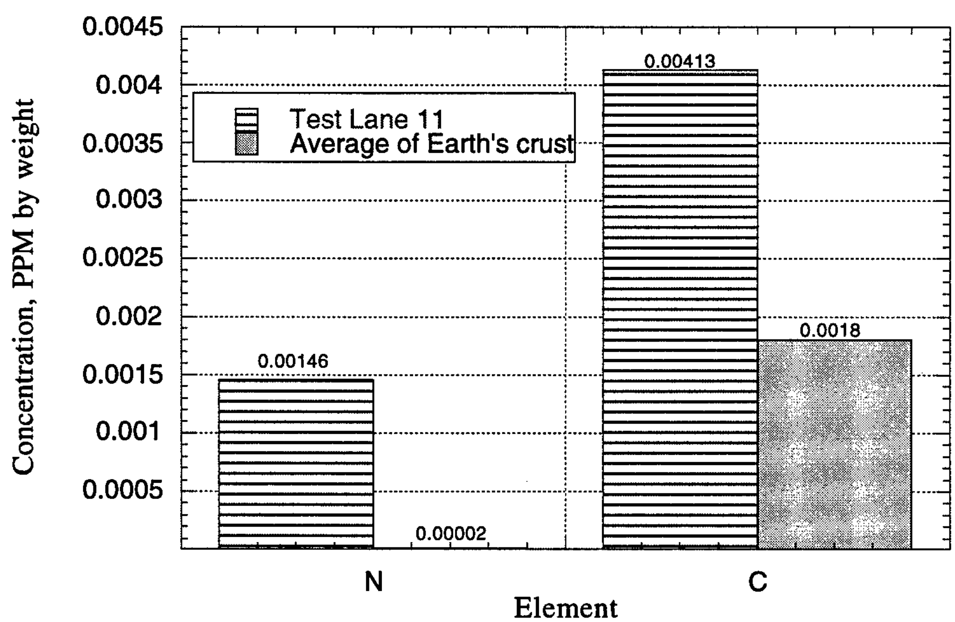


Figure IV-9. Soil Composition, Lane 11 and Earth's Crust (avg): Nitrogen and Carbon

method to nitrogen content in the soil. Carbon content in the soil may have a modest positive impact on TNA systems because it will moderate the neutrons to some degree, and it has a very low absorption cross-section. The fact that the carbon levels in the test lane were about a factor of two higher than the average values quoted for Earth's crust may have helped the TNA performance to some degree.

B. SOCORRO

All of the 19 mines were detected. Of the 19 false locations, 6 (or 32 percent) were declared as mines. The 19 detections included 1 case where CDC indicated a possible hit that was probably outside the nominal 30-cm range of the system. Nevertheless, after the marked location was checked by hand to verify that it was within 5 cm of the intended location, the report was scored as a correct detection.

V. FINDINGS AND RECOMMENDATION

A. FINDINGS

We summarize our findings as follows:

1. Aberdeen

- $P_D = 12/19$, $P_{FA} = 0/22$.
- ROC curve (reported previously) showed $P_D = 15/19$ was attainable before the first false alarm.
- Alternative approaches showed little sensitivity of the ROC curve to the details of the sensor reporting algorithm.
- Surface mines were detected with greater certainty than buried mines, although one surface mine gave trouble.
- Detectability of buried mines showed no dependence on depth.
- Detectability of buried mines showed no dependence on mine type (or nitrogen content).
- The departure from near-perfect performance was dominated by three mines—M19 at 1.5 in., TM62P at 0 in., and TM46 at 2 in.
- Target signature variability played a larger role than background variability.
- It is possible that the square shape of an M19 renders it more difficult to detect. An M19 on the surface yielded the second weakest signal of all the surface mines; its signal was even weaker than those of a TM62M and a TMA4, both of which contain significantly less nitrogen than an M19. Furthermore, during a separate reproducibility test, an M19 at 1.5 in. twice yielded a significantly weaker signal than an M15 at 1.5 in., even though the M15 contains only 10 percent more nitrogen than an M19.
- The variability of mines on the surface was particularly troubling.
- Test execution shortfalls preclude resolution of key issues.

2. Socorro

- $P_D = 19/19$, $P_{FA} = 6/19$.
- Test execution shortfalls preclude further analysis.

B. RECOMMENDATION

The signature variability that is seen in this data is unique. The background phenomenology, usually the performance driver, seems to be under control, at least at this particular location (Aberdeen). The target signatures, however, which are usually well modeled and fairly reproducible, are extremely variable. That significant variability is in a set of mines on the surface is particularly bewildering.

Unfortunately, aspects of the test that were intended to shed light on exactly these issues were not completed. It is of interest to the Army to determine whether these issues are subject to amelioration by means of engineering expedients or represent fundamental obstacles to future improvement. We recommend that resolution of these issues by further testing precede further development of this system. Appendix A describes such a test.

APPENDIX A

TEST PLAN

APPENDIX A
TEST PLAN

The paragraphs that follow comprise the original test plan for this neutron activiation study. It differs substantially from what was actually accomplished in the field; for that information see the main text. It is included to clarify the intent of the various phases of the test.

There are four objectives of this experiment, each of which is addressed in a separate phase. The Phase 1 activities comprise a set of soil assays that do not require the availability of the mine detection system or its developers. The other three phases consist of a series of 2-minute "measurements" by the mine detection system at designated (i.e., flagged) measurement locations.

PHASE 1: SITE CHARACTERIZATION

The question of how much variability in neutron activation signature is to be expected on a given site has not yet been addressed. This goes to the important question of what is possible given optimal performance of the mine detection system. For example, soil nitrogen content is itself highly variable on a global scale; local variations will be an uncontrollable system driver, as will silica density. A measurement of site composition will be conducted to enable modeling of "ideal" system performance.

The soil sampling protocol is as follows: One hundred sampling sites will be uniformly distributed in distance along test lanes. At every 10th site, 5 samples will be taken at the vertices of a pentagon roughly 6 in. on a side; at each of the other sites only one sample will be taken (see Figure A-1). For each sample, the location, volume, and weight will be recorded on site, and the sample bagged. Then the samples will be shipped to the analysis facility, where each will be analyzed for water, nitrogen, silicon, iron, boron, hydrogen, aluminum, calcium, sodium, potassium, titanium, and gadolinium.

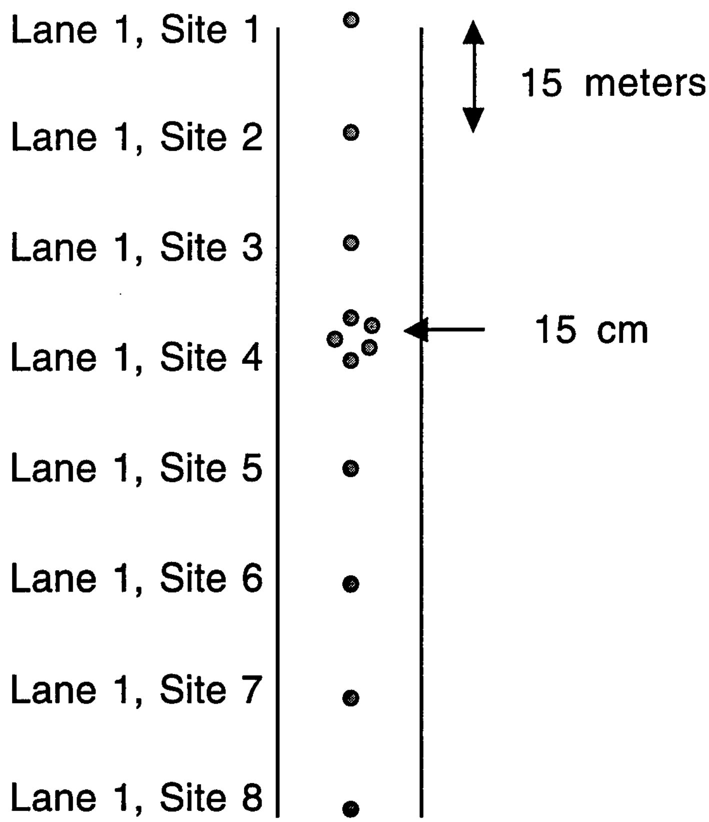


Figure A-1. Illustration of Sample Spacing for the Phase 1 Site Characterization Study

PHASE 2: REPRODUCIBILITY

Previous experience with tests of neutron activation systems make reproducibility study an explicit requirement of a successful test. Without an understanding of the reproducibility of measurements, none of the other measurements are meaningful. Both short- and long-term stability will be assessed in Phase 2.

The reproducibility will be assessed early in the test, with ongoing spot checks to monitor possible drift. The initial assessment will consist of five repetitions of measurements on a series of four test locations (see Figure A-2). Two of the test locations will have buried mines (or surrogate targets of melamine [$C_3N_3(NH_2)_3$] nominally sized for a 2-kg nitrogen content). The mine-detection system measurements will be made serially; that is, the system must move and be realigned between measurements of the same location so that the uncertainties associated with alignment are incorporated in the reproducibility study. Subsequently, at roughly 2-hour intervals, the reproducibility site will be revisited for single passes over each of the four test locations to assess longer term reproducibility.

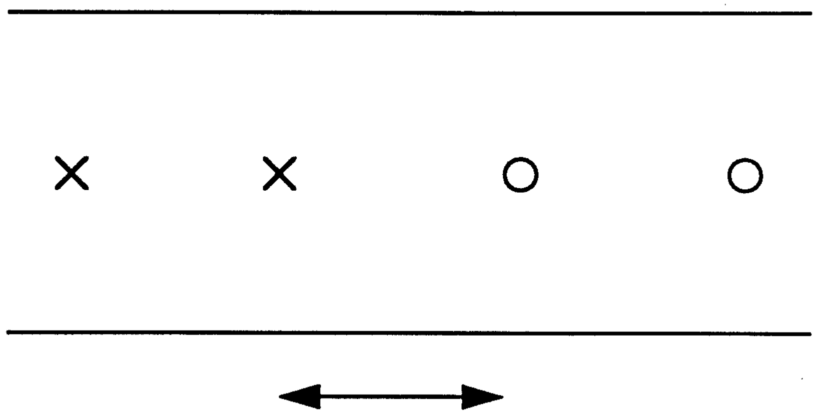


Figure A-2. Illustration of Laydown for Reproducibility Study. The X's denote flagged locations with buried mines, the O's flagged locations without mines. The separation between the locations needs to be greater than 3 m.

PHASE 3: SPATIAL RESPONSE

Neutron activation is not envisioned as a tool for wide-area search, but rather as a confirmatory technique. Thus, the neutron activiation system will be cued by other sensors. The spatial accuracy of the cue must therefore be well matched to the spatial response of the TNA system. In Phase 3 the spatial response function of the detection system will be determined.

The test array is a series of "columns" of test locations (see Figure A-3). Nominally, each column is a set of four test locations. Typically, one of these is a surrogate target, and the other three are at various distances from the target, although occasionally a column does not contain a surrogate at all. Again, a melamine target surrogate may be used. The purpose of the "column" configuration is to save time when evaluating the spatial response profile. The arrangement allows the four sites per column to be aligned using the lateral play of the system without moving the vehicle.

The initial test will evaluate the spatial response over an array of five columns. On-site analysis will determine whether and how additional measurements will be needed. Depending on the behavior of the system, up to 25 columns may need to be evaluated.

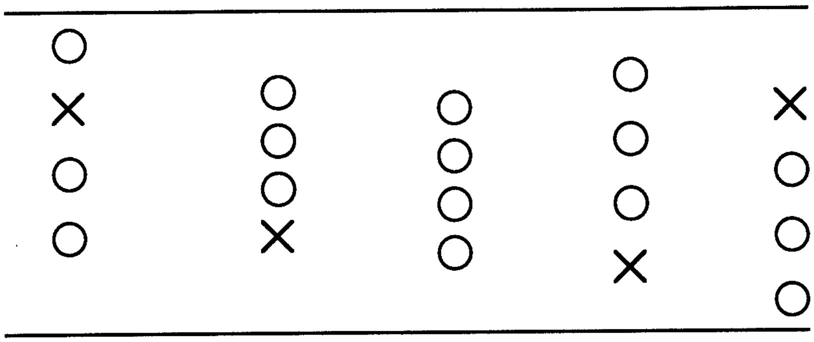


Figure A-3. Illustration of Test Columns for Spatial Response Test. X's and O's denote flagged locations with and without buried mine surrogates, respectively.

PHASE 4: RECEIVER OPERATING CHARACTERISTIC

The test site will include mines of various types, buried at different depths (see Figure A-4). The site will also include a number of sites with no mine present. The ROC curves will be done by mine type/depth, and various combinations. The full test will require about 160 measurements. Limiting the test to a subset corresponding to the plastic casings would pare the number to about 80. It is important that if the test is truncated, the number of mine types must be limited; the number per type is already so small as to be a problem.

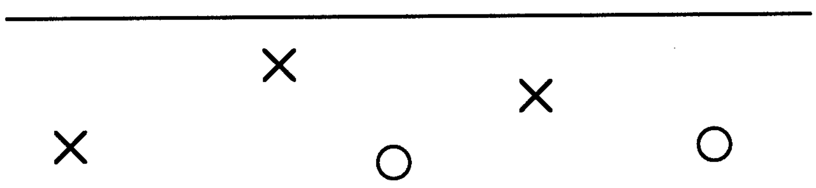


Figure A-4. Illustration of Laydown for ROC Study. The X's denote flagged locations with buried mines, the O's flagged locations without mines.

REPORTING REQUIREMENT

To enable trade studies that will assess costs associated with leakage and false alarms, the test methodology will focus on generation of a ROC curve. This means that simple binary reports are inadequate. Measurement reports must be in a continuous variable that is monotonic in the likelihood that a mine is present, which enables setting the decision threshold off-line. (We are being deliberately vague about the precise meaning of the likelihood variable that will be reported, so as not to limit the options for the system developers. For example, the likelihood variable might be counts above background in some energy range.)

The likelihood statistic should be generated autonomously (that is, without human intervention) at the end of a fixed counting time (nominally, 2 minutes for this test).

To assess the validity of efforts to model TNA system performance, the gamma spectrum at each designated measurement site will be required.

SCHEDULE

The test schedule needs to balance the various objectives and minimize the risk that any objective is neglected. All of the objectives are important; "good enough" on all four objectives is preferable to failure on any.

The schedule therefore begins with an hour of the reproducibility phase; unless there are reproducibility problems this should be enough to quantify the variances. Next, an hour to an hour and a half of spatial response study should suffice to make quantitative estimates of a response function and determine the need for additional data. Meanwhile, the ROC determination can proceed on the priority subset of test sites (color-coded flagging is suggested for first pass/second pass measurements).

Phase 1 is independent of the mine detection system and can therefore be scheduled independently. Phases 2, 3, and 4 all exercise the detection system, so they need to be scheduled serially. The schedule will interleave the phases to optimize value added, given the possibility that time or equipment constraints may mandate partial completion of the baseline test.

APPENDIX B

ABERDEEN DATA

APPENDIX B
ABERDEEN DATA

Table B-1 is a summary table containing the relevant data from Aberdeen Proving Ground. It has been sorted by P_{min}, which is the statistic used by CDC to determine whether there was a mine present. The "Truth" column contains a 1 if the target was a mine and a zero otherwise. "Net D1" refers to the net counts in detector 1, and so on for the other detectors, while "Bck D1" refers to the background counts in detector 1, and so on for the other detectors. "Pa D1" is the value of the P-statistic for detector 1, and so on for the other detectors.

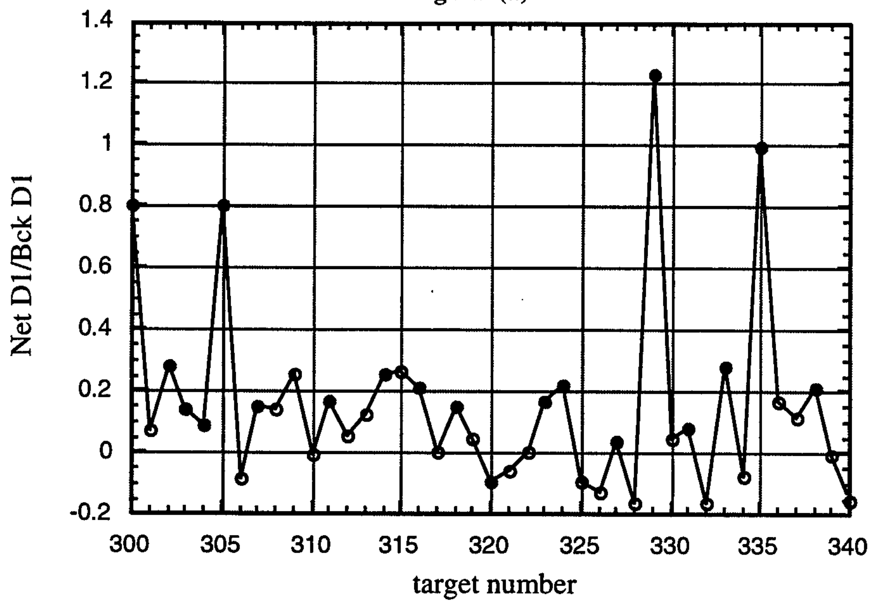
Figures based on this data follow Table B-1. Figures B-1(a)–(d) present the Net counts/Background counts in each detector versus targets arranged sequentially in time, while Figure B-1(e) presents the Net/Background counts summed over all detectors versus target number. The filled-in circles represent those targets that were actually mines. The mines that yielded the lowest signatures correspond to target numbers 311, 320, and 314. Note that there is nothing to distinguish these points from the nearby background measurements. Figures B-2(a)–(d) present the Net counts/Background counts in each detector versus the rank ordering by P_{min}, and Figure B-2(e) presents the Net/Background counts summed over all detectors versus the P_{min} rank ordering. The filled-in circles once again represent those targets that were actually mines.

In Figures B-3(a)–(f) we explore the correlations of the P-statistics in the various detectors. The correlations are not strong; however, when the correlations of the net-to-background counts in the various detectors are examined, as in Figures B-4(a)–(f), the correlations are much stronger.

Table B-1. APG Summary Table

Target	Pmin	Truth	ID	Net D1	Net D2	Net D3	Net D4	Sum Net	Bck D1	Bck D2	Bck D3	Bck D4	Sum Bck	Pa D1	Pa D2	Pa D3	Pa D4
300	0.0000	1	TM62M S	86.82	324.89	78.73	38.04	528.48	108.2	111.1	63.3	85	367.6	0	0	0	0.001
305		1	M15 S	84.88	220.68	81.13	61.71	448.41	106.1	108.3	61.9	84.3	360.6	0	0	0	0
329	0.0000	1	TM62M S	145.33	93.71	83.66	122.71	445.4	117.7	105.3	69.3	104.3	396.6	0	0	0	0
335	0.0000	1	M15 S	119.79	110.34	111.62	131.33	473.09	120.2	109.7	74.4	101.7	406	0	0	0	0
304	0.0000	1	M15 1.5″	9.82	117.59	40.39	21.77	189.56	104.2	107.4	60.6	82.2	354.4	0.216	0	0	0.032
302	0.0000	1	TM62M 4″	29.91	102.03	25.82	19.73	177.49	105.1	108	61.2	83.3	357.6	0.012	0	0.007	0.046
333	0.0000	1	M15 1.5″	32.95	67.4	38.27	41	179.62	118	108.6	72.7	99	398.3	0.01	0	0.001	0.001
323	0.0000	1	M15 1.5″	20.4	86.67	12.78	31.99	151.83	121.6	87.3	64.2	103	376.1	0.07	0	0.104	0.008
324	0.0000	1	TMA4 S	27.58	62.21	39.68	30.97	160.44	127.4	90.8	67.3	108	393.5	0.028	0	0	0.011
303	0.0000	1	TM62P 3″	15.31	74.88	16.17	−10.97	95.4	105.7	109.1	61.8	83	359.6	0.116	0	0.056	0.857
316	0.0001	1	M19 S	27.57	36.43	27.62	4.92	96.54	129.4	103.6	67.4	103.1	403.5	0.029	0.004	0.007	0.345
307	0.0004	1	M19 1.5″	15.92	51.65	3.82	−19.54	51.84	107.1	130.4	75.2	92.5	405.2	0.109	0	0.358	0.968
327	0.0024	1	TM62P 3″	3.85	16.36	11.53	38	69.74	115.1	104.6	68.5	102	390.2	0.382	0.1	0.133	0.002
338	0.0035	1	M19 1.5″	23.69	39.25	2.38	5.01	70.32	111.3	123.7	79.6	118	432.6	0.039	0.004	0.412	0.351
318	0.0113	1	TMA4 2″	18.24	15.15	4.64	16.7	54.73	118.8	96.8	62.4	94.3	372.3	0.09	0.109	0.314	0.085
322	0.0178	0		0.23	25.54	5.02	−14.68	16.11	121.8	87.5	64	102.7	376	0.493	0.018	0.303	0.902
326	0.0196	0		−14.68	18.71	0.48	26.66	31.17	113.7	103.3	67.5	100.3	384.8	0.889	0.071	0.481	0.02
315	0.0212	0		26	−24.5	21.67	21.65	44.82	99	130.5	68.3	85.4	383.2	0.021	0.974	0.023	0.034
309	0.0219	0	TM62MI 2″	26.38	−1.17	−7.03	1.24	19.42	103.6	126.2	73	89.8	392.6	0.022	0.535	0.764	0.456
331	0.0229	1	TM62M 4″	9.57	19.08	7.09	13.59	49.33	118.4	108.9	72.9	99.4	399.6	0.235	0.073	0.249	0.136
314	0.0236	1	TM46 2″	25.46	−18.87	−1.32	2.42	7.69	99.5	129.9	68.3	85.6	383.3	0.024	0.931	0.554	0.413
339	0.0472	0		−0.4	4.02	18.83	−22.68	−0.22	108.4	121	77.2	113.7	420.3	0.513	0.38	0.047	0.974
337	0.0510	0	TM62MI 2″	12.6	20.82	3.82	3.82	41.07	108.4	121.2	77.2	114.2	421	0.163	0.066	0.359	0.383
308	0.0706	0		15.06	20.67	−1.08	−15.93	18.72	103.9	126.3	73.1	89.9	393.2	0.117	0.071	0.543	0.936
320	0.0760	1	M19 1.5″	−11.2	6.32	14.71	−9.65	0.18	123.2	99.7	64.3	97.7	384.9	0.81	0.301	0.076	0.803
336	0.0776	0		18.56	17.62	10.52	−12.21	34.48	108.4	121.4	77.5	114.2	421.5	0.078	0.099	0.167	0.842
325	0.0852	0		−11.34	16.18	2.87	−3.87	3.83	122.3	87.8	64.1	102.9	377.1	0.815	0.085	0.383	0.628
311	0.0882	1	TM62P S	17.59	−45.43	8.14	4.62	−15.07	106.4	138.4	72.9	91.4	409.1	0.088	1	0.221	0.345
301	0.0957	0		7.7	15.36	9.88	−3.13	29.81	103.3	106.6	60.1	81.1	351.1	0.266	0.115	0.154	0.617
313	0.1542	0		12.54	−26.36	7.39	−16.52	−22.95	99.5	131.4	68.6	85.5	385	0.154	0.982	0.234	0.948
334	0.1593	0		−9.4	−0.47	10.55	4.82	5.5	117.4	108.5	72.5	98.2	396.6	0.775	0.515	0.159	0.343
306	0.1760	0		−8.22	5.78	9.78	−11.48	−4.15	102.2	125.2	72.2	88.5	388.1	0.761	0.334	0.176	0.861
332	0.1872	0		−19.13	11.36	6.27	−8.7	−10.2	118.1	108.6	72.7	98.7	398.1	0.943	0.187	0.273	0.777
321	0.1935	0	M15I S	−5.68	1.59	3.23	10.13	9.27	100.7	114.4	70.8	90.9	376.8	0.688	0.45	0.374	0.194
328	0.2347	0		−18.24	8.5	7.25	−2.68	−5.17	112.2	102.5	66.7	98.7	380.1	0.94	0.245	0.235	0.591
312	0.2426	0		5.83	−40.64	1.73	7.86	−25.22	99.2	131.6	68.3	85.1	384.2	0.314	1	0.43	0.243
319	0.3004	0		5.83	−5.75	−7.56	6.17	−1.3	119.2	96.8	62.6	94.8	373.4	0.329	0.693	0.801	0.3
317	0.3108	0	M19I 2″	0.18	−6.98	−8.4	5.86	−9.34	120.8	98	63.4	96.1	378.3	0.495	0.729	0.825	0.311
330	0.3296	0	M15I 1.5″	5.65	1.49	2.88	−8.4	1.62	113.3	102.5	67.1	100.4	383.3	0.329	0.451	0.385	0.768
340	0.3941	0	EM12 S	−17.06	−2.78	2.85	−18.49	−35.49	109.1	121.8	78.2	115.5	424.6	0.928	0.585	0.394	0.938
310	0.5080	0		−0.24	−22.56	−15.82	−23.41	−62.03	103.2	127.6	72.8	89.4	393	0.508	0.964	0.956	0.99

Fig B.1 (a)



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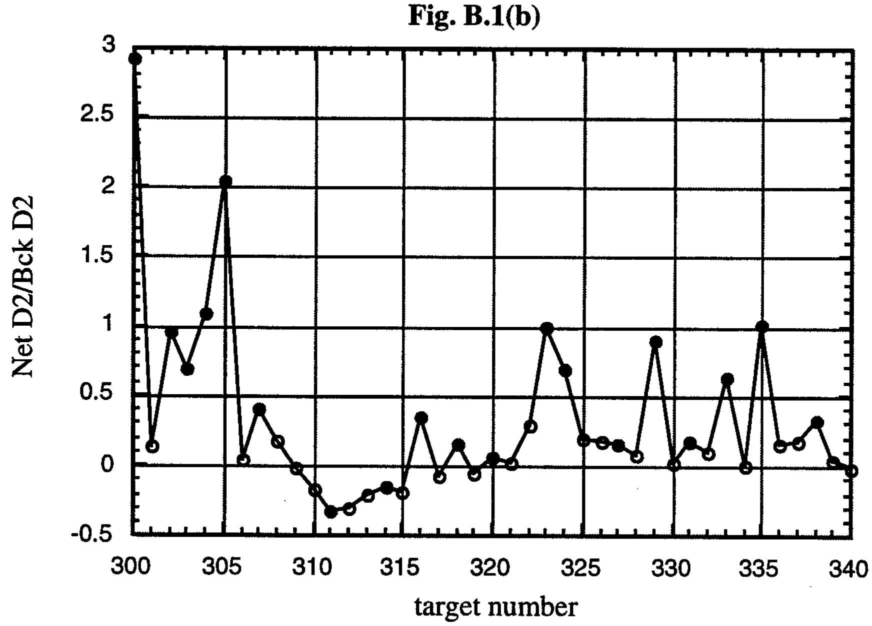

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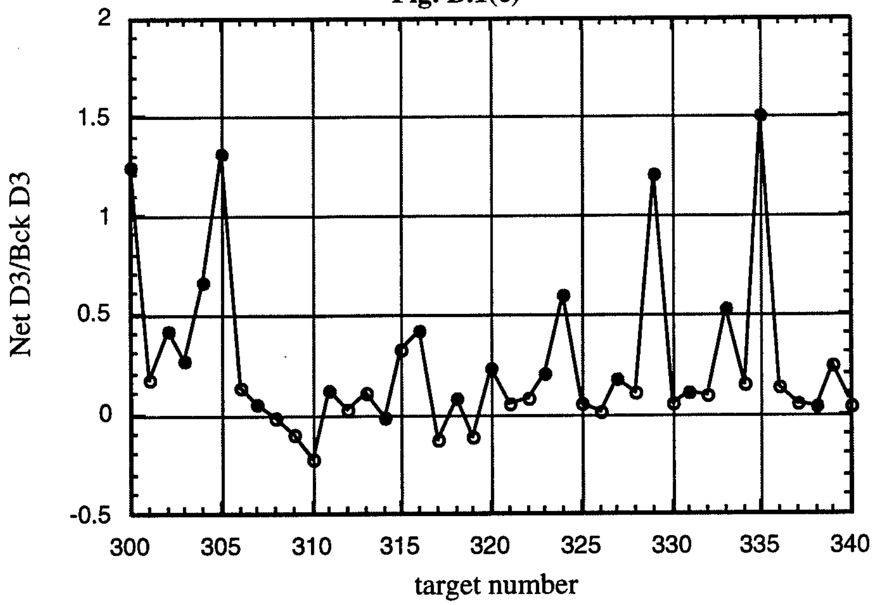

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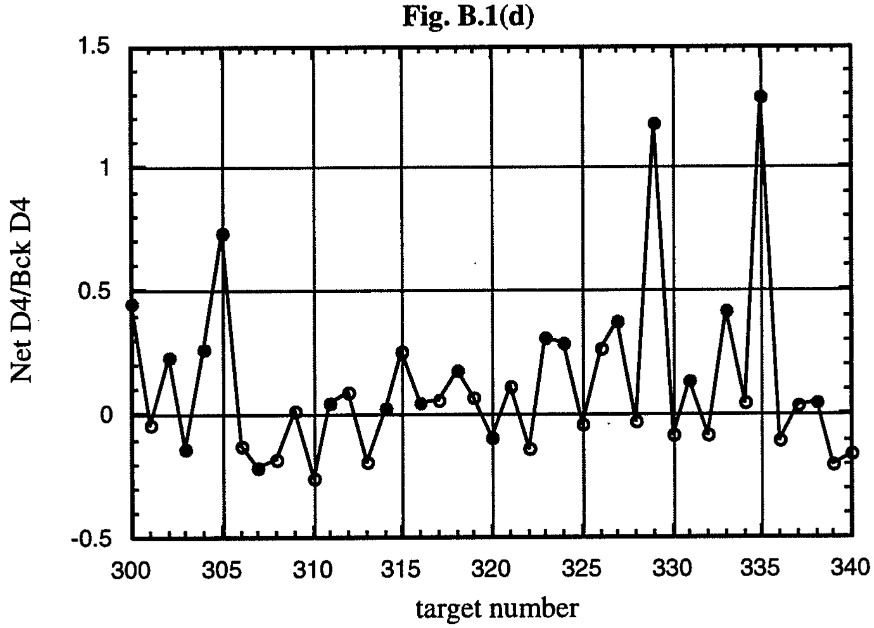

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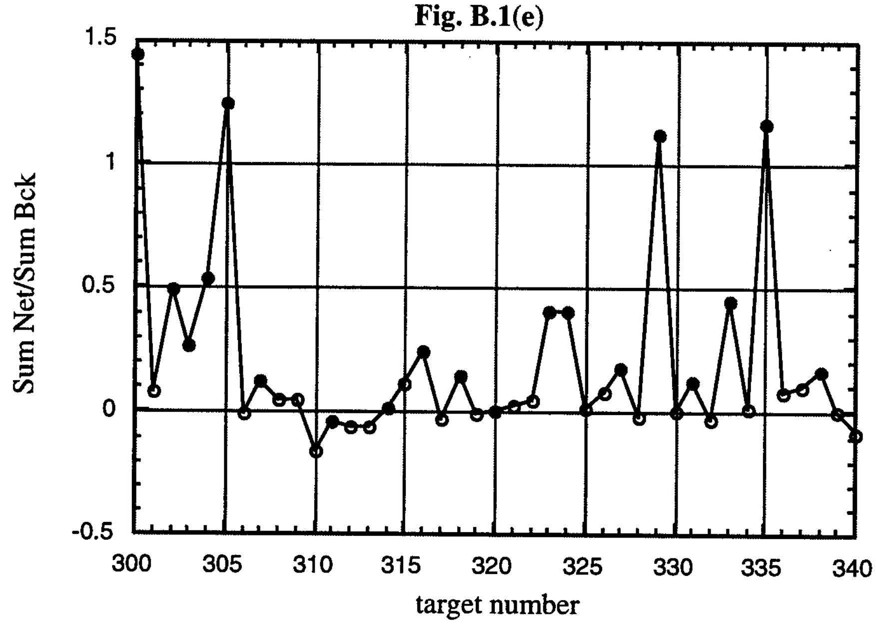

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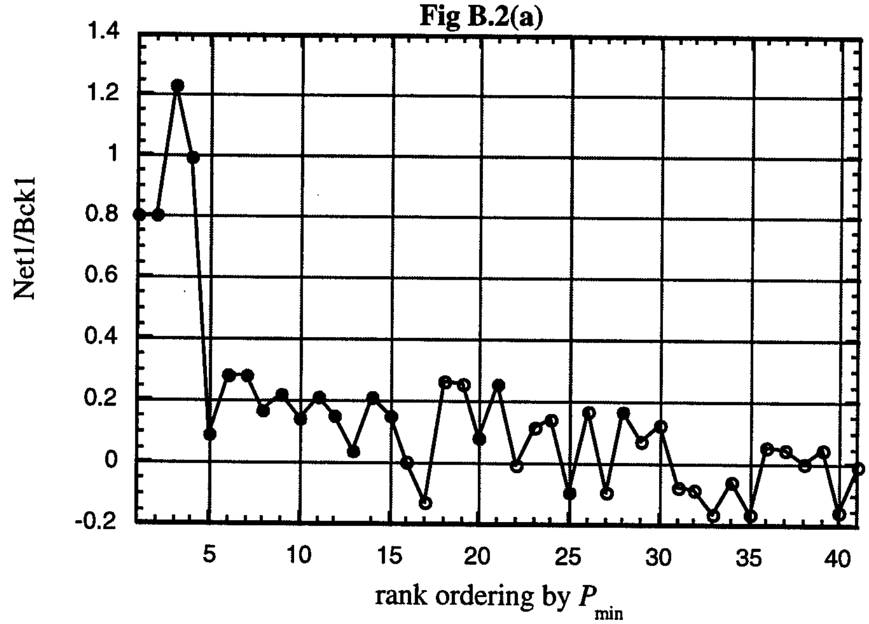

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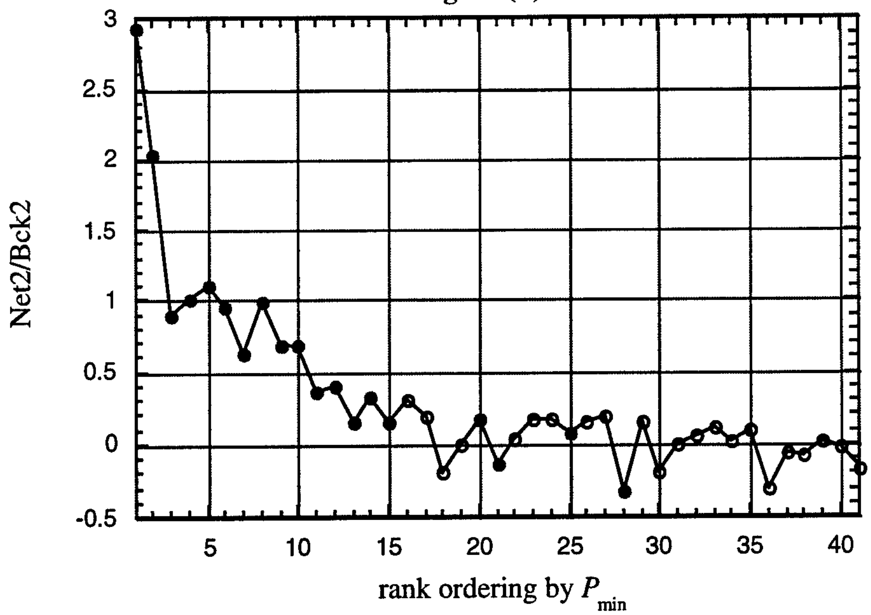

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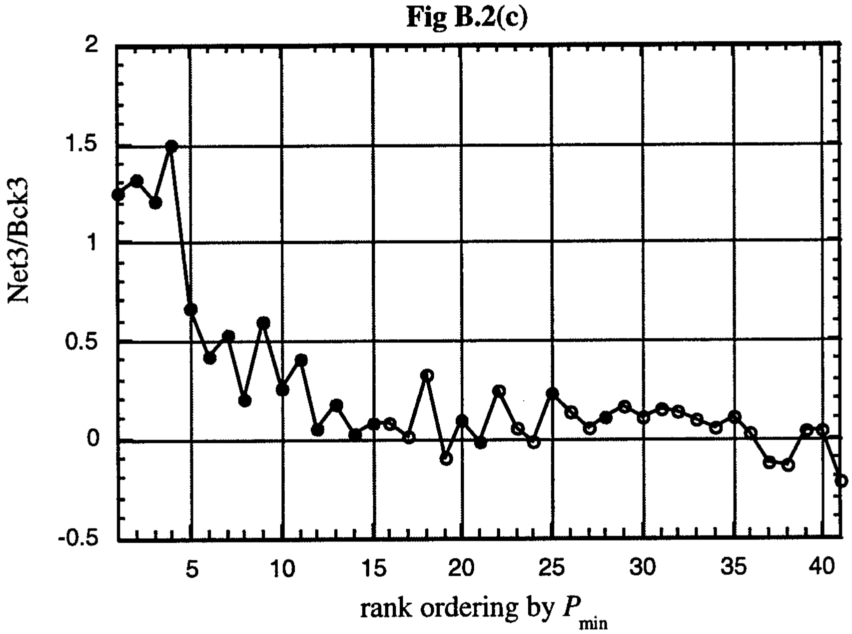

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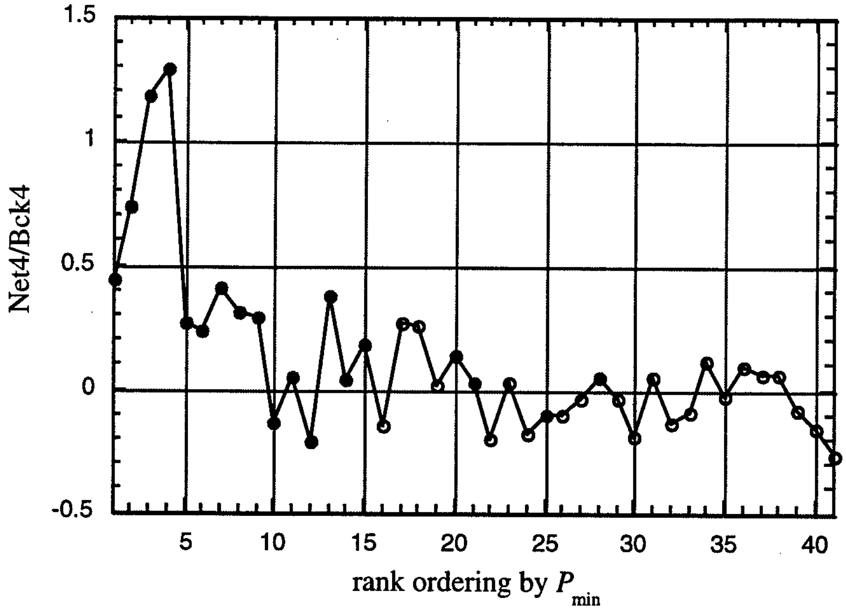

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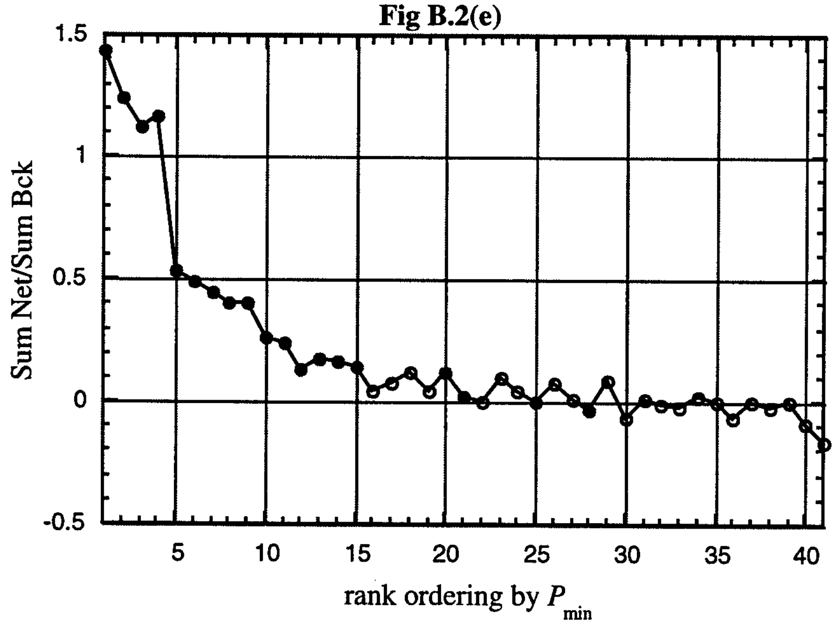

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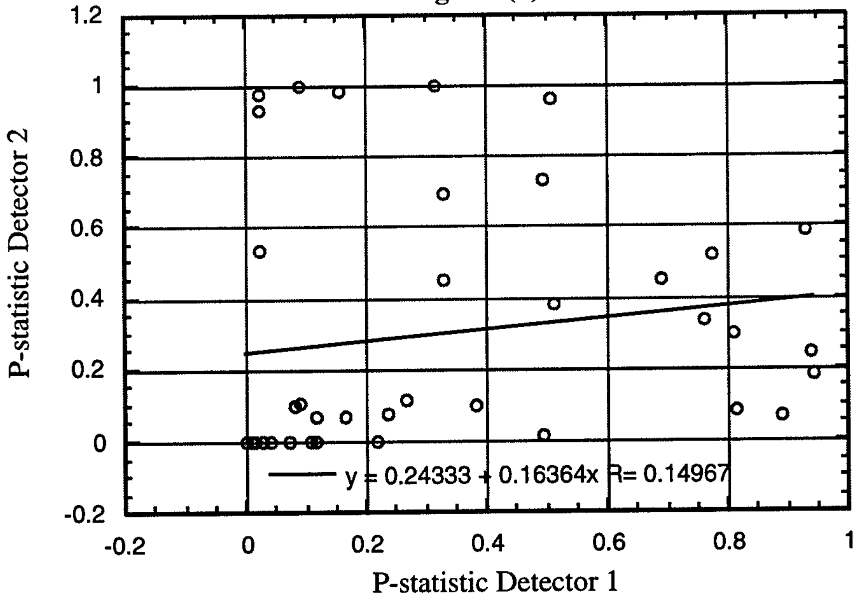

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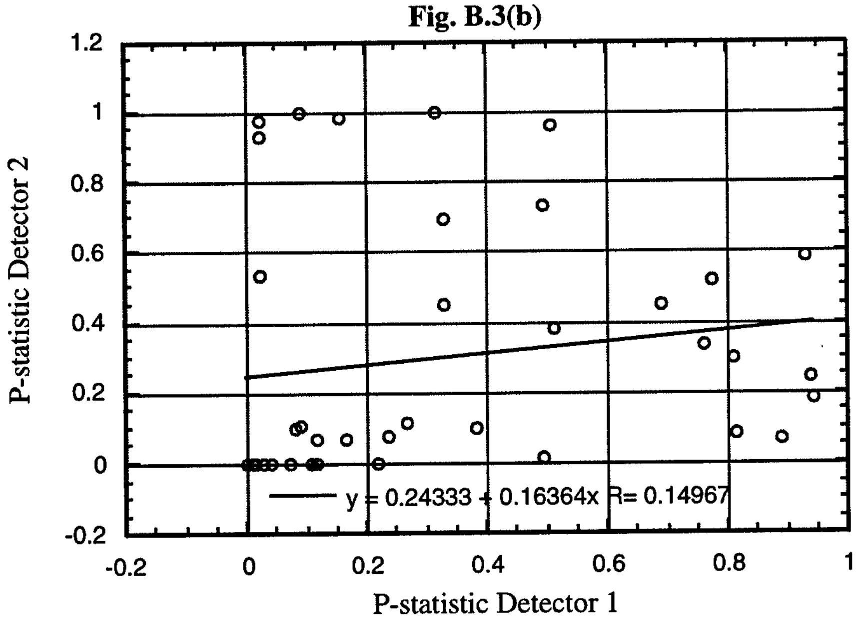

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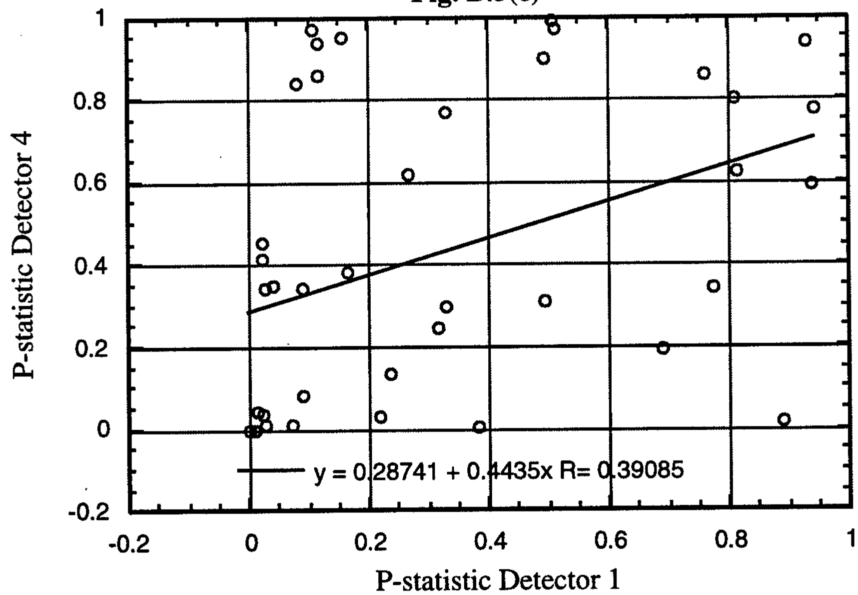

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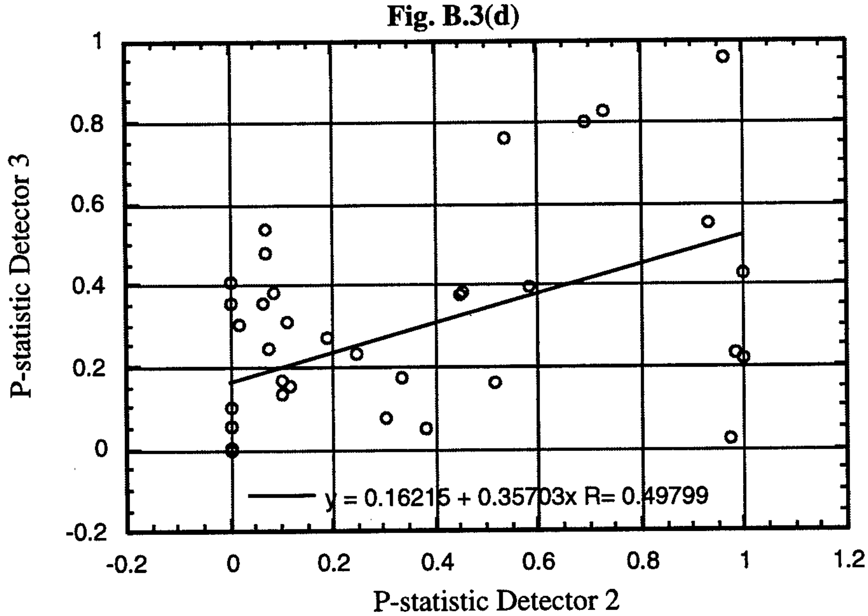

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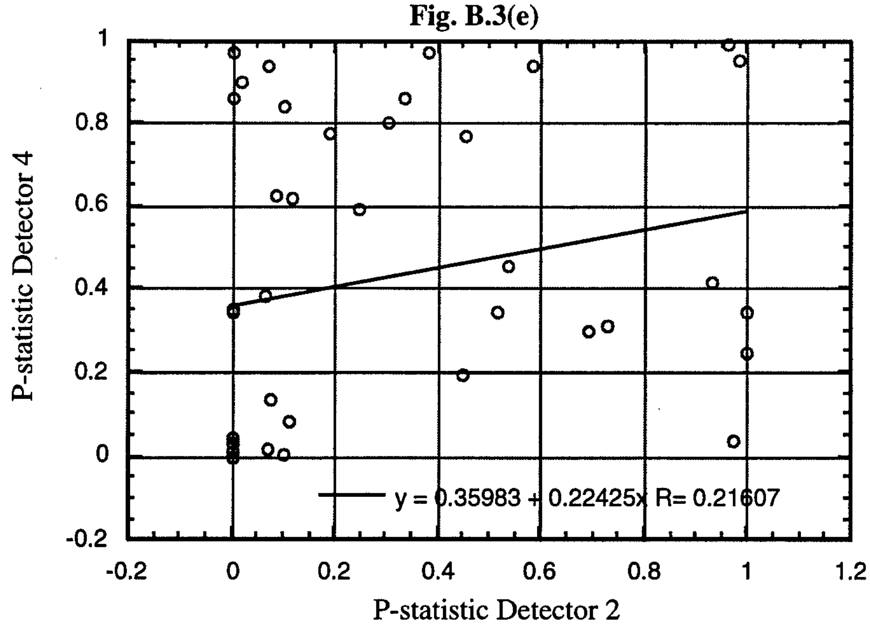

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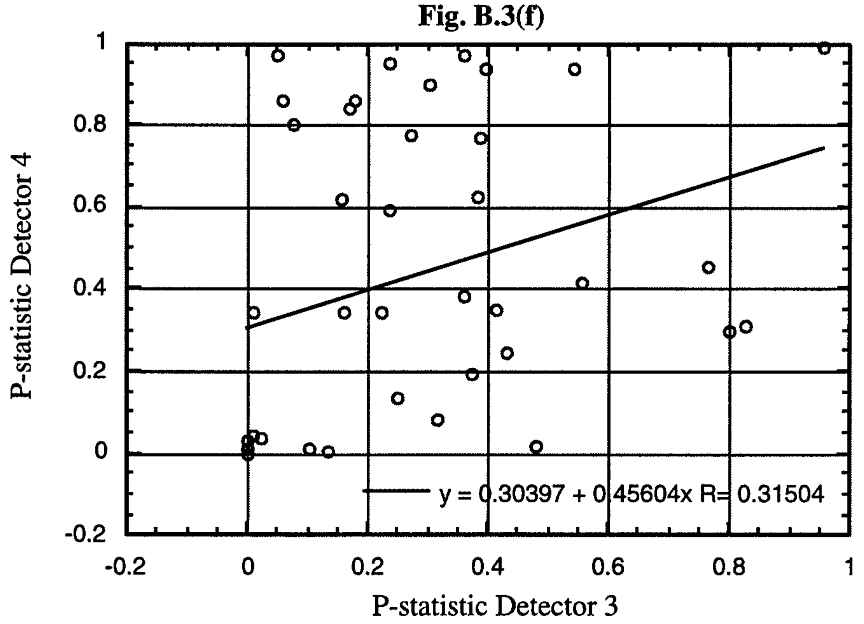

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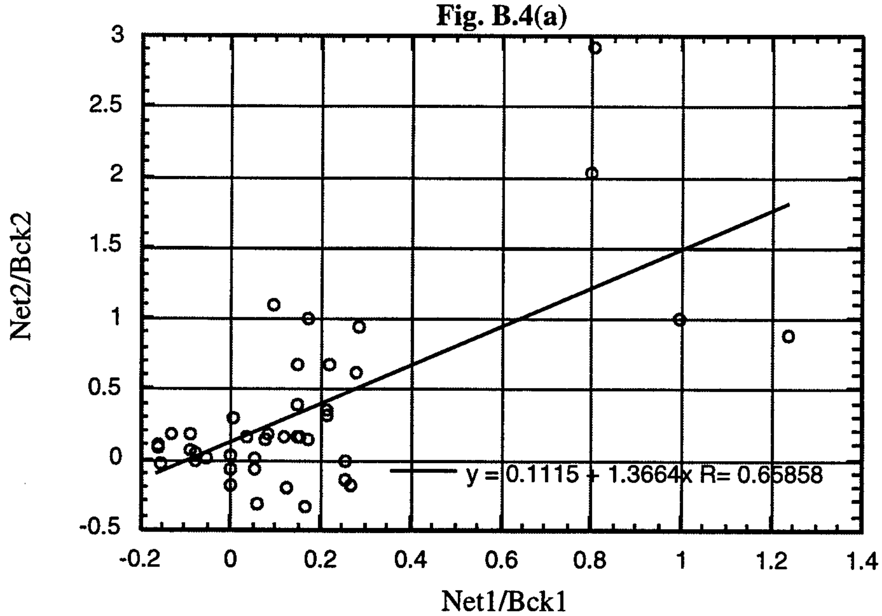

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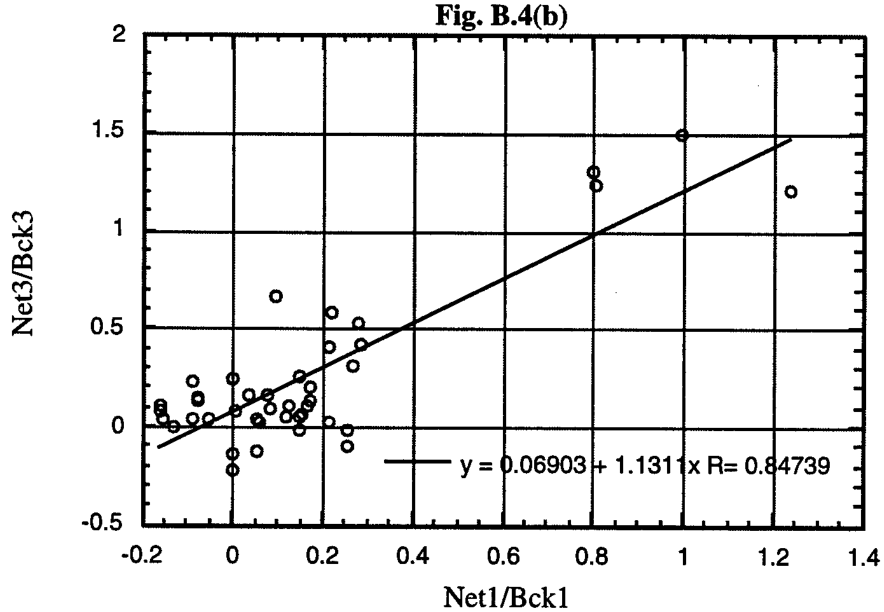

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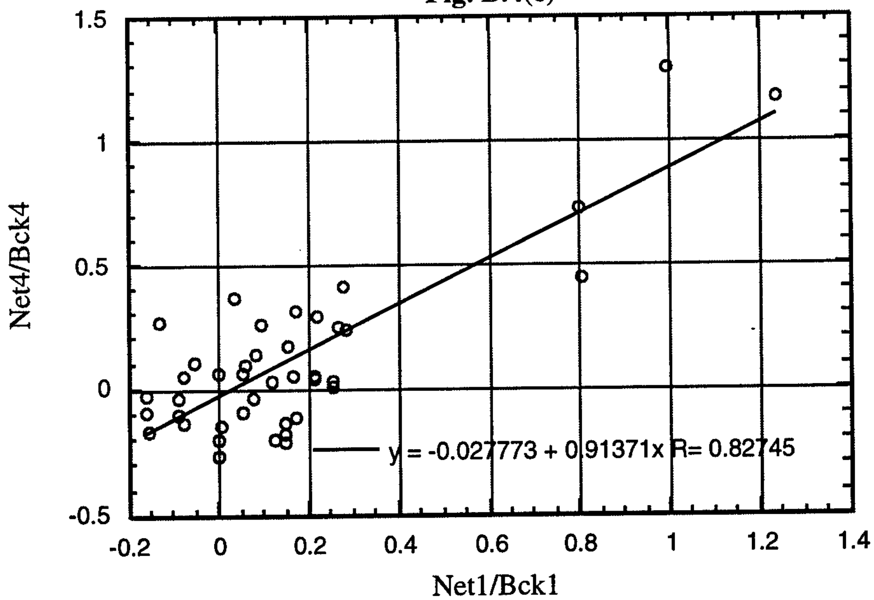

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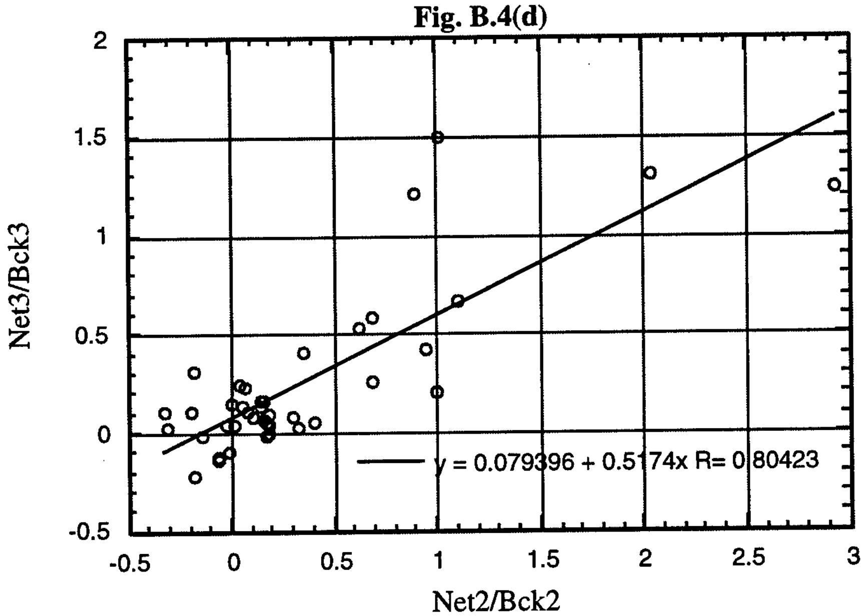

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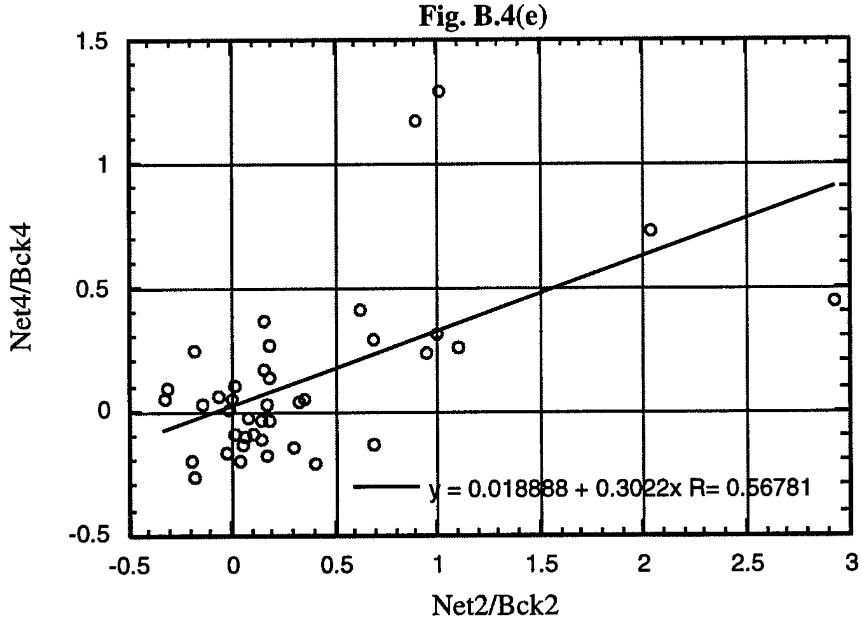

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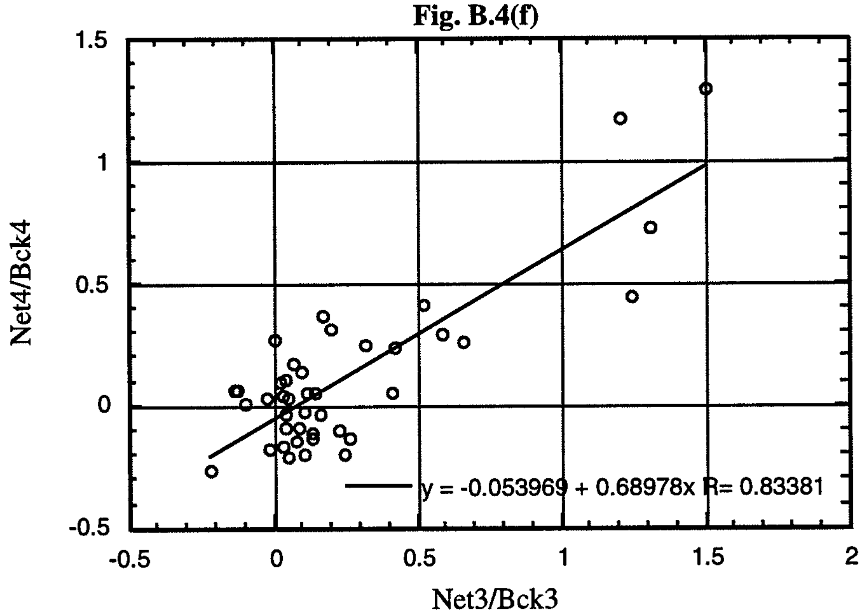

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13. ABSTRACT *(Maximum 180 words)*

This report discusses the results of a series of tests specific to the Thermal Neutron Analysis (TNA) detector being used by Computing Devices Canada (CDC) during the Vehicular Mounted Mine Detector (VMMD) ATD demonstrations conducted at Aberdeen Proving Ground (APG), Maryland, in June 1998 and at Socorro, New Mexico, in July 1998. A TNA-specific test plan was devised to address performance issues in a thorough and systematic manner; unfortunately, there were sufficient constraints such that the test plan was not implemented as designed. Instead, a much-abridged version was conducted at APG, and a still more limited version at Socorro. In addition to performance evaluation for both sites, we present detailed analysis of the APG data, where we found that the detectability of a mine did not seem to depend on either its burial depth or its nitrogen content. Furthermore, target signature variability dominated the test results, rather than background variability. Surprising results such as these must be treated with caution, however, given the extremely small data set that was available. We believe that it is in the Army's interest to pursue these issues with a more thorough test, such as the one originally proposed which appears in the Appendix of this report.

14. SUBJECT TERMS
mine detection, thermal neutron analysis, prompt-gamma neutron activation analysis

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